Blast injury to the human skeleton: Recognition, identification and differentiation using morphological and statistical approaches.

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Abstract

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Anthropologists are increasingly called upon to assess trauma to the skeleton and contextualising the nature of this trauma. Blast injury is a type of trauma which is increasingly seen in a variety of contexts, such as terrorism, human rights violations, combat and accidents. The purpose of this study was to examine blast injury in the human skeleton and apply robust multivariate statistical methods, alongside morphological methods, to identify blast trauma based on the distribution of injury in the skeleton. The objectives of the study were to identify patterns in a sample of cases from mass graves in Bosnia and to determine differences between the blast injury cases and gunshot wound cases which can identify indicators of blast injury for future use. This was done using Pearson's χ^2, cluster analysis and multiple correspondence analysis. Secondly, the identified indicators were applied to two methods of binary logistic regression model to test prediction of the presence or absence of blast injury in the sample, as well as assessing the results of the two methods. Lastly, the results of these analyses were subsequently compared with clinical literature to identify similarities and differences which can aid anthropologists in determining presence of blast injury in large assemblages. This also served to address the specific argument that the injuries seen in the Bosnia sample are combat related, as claimed in court proceedings in ongoing cases at the International Criminal Tribunal for the Former Yugoslavia.

It was found that cluster analysis was not useful for the sample examined in the research, however multiple correspondence analysis permitted graphical differentiation between the blast injury and gunshot cases, identifying variables which contributed to the variance and could be used as indicators of blast injury. Binary logistic regression was employed to test the significant contribution of these variables to a model predicting the presence of blast injury in a sample. It was found that presence of trauma to the right shoulder girdle, left forearm, vertebrae, right pelvis and left femur could indicate the presence of blast injury in an assemblage, with correct average classification in 74.86% of cases. The prevalence of trauma in the Bosnia sample was compared with examples from terrorist incidents and

combat situations to identify similarities and differences between these and found that there significant differences in the prevalence of trauma in the Bosnia sample. This highlights that this sample does not resemble any combat patterns of injury, answering the question posed in ICTY court proceedings.

This work contributes new knowledge to anthropology on the identification and differentiation of blast injury in assemblages as well as demonstrating the use of multivariate statistical methods for trauma analysis. These results can be applied to anthropological investigation of historical contexts as well the modern investigations which will require knowledge of blast injury currently and in the future.

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Author's declaration

I declare that the work presented in this thesis is my own work with the exception of the following, for which the author led all aspects of the preparation of this work:

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1. Introduction

The examination of blast injury in the context of forensic and biological anthropology serves many important purposes relevant to different aspects of the discipline such as the investigation of mass graves, human rights violations, inter-personal violence and historical investigation. Identification of trauma in the examination of post-mortem human remains is one of the tasks of the anthropologist and plays an important role in contextualising the finds. Accurate identification of peri-mortem trauma requires expertise with basic trauma mechanisms affecting the skeleton, such as the biomechanics of fracturing. Furthermore, specific injuries sustained from sharp, blunt or ballistic mechanisms are an additional area of expertise required from the anthropologist.

Of recent interest is blast injury, not reserved solely for the medical community, but increasingly familiar to the anthropologist through work ranging from recovery in historical battles to modern conflict, human rights work and terrorism (Baraybar and Gasior 2006; Kimmerle and Baraybar 2008; Wessling and Loe 2011; Appleby et al. 2012; Christensen and Smith 2012; Christensen et al. 2012). Despite the increasing number of situations in which the anthropologist may encounter blast injury, there is a lack of published information regarding this type of trauma in the anthropological literature. More recently Christensen *et al.* (2012) demonstrated patterns of injury in a controlled blast environment using porcine analogues.

It is critical to expand the body of knowledge for anthropologists by beginning with a review of the history and development of explosives, the chemistry and physics which impart specific wounding characteristics and the resulting patterns of injury as describe in the studies available, from the clinical literature. By exploring these and relating them to the identification of blast injury in post-mortem skeletonised remains, the anthropologist can contribute to the contextualisation of cases being investigated.

The primary aim of this project is to apply robust multivariate statistical methods, alongside morphological methods to identify blast trauma from the distribution of injuries throughout the skeleton in cases related to the Kravica warehouse in Bosnia and Herzegovina. Whilst this objective might be more difficult to achieve in individual cases it may be feasible with an acceptable degree of probability in reasonably sized samples. The recognition, differentiation and quantification of blast injury versus other trauma, particularly gunshot wound related deaths, is examined. The establishment of guidance for the identification of blast injury in skeletal assemblages is a main component of this piece of research. This is accomplished through four primary objectives:

1. An exploration of patterns of injury previously published in clinical literature.
2. The establishment of a statistical methodology to compare observed patterns of injury in assemblages for the purpose of identification and comparison of blast injury in various contexts.
3. Application of the statistical methodology to the discrimination of blast injury from gunshot wound related deaths with the purpose of providing indicators to differentiate the two types of trauma.
4. Application of the statistical methodology to a large scale assemblage, comprised of cases related to the Kravica warehouse in Bosnia and its associated mass graves, to explore the patterns present and compare these to the previously published data in the clinical literature to assess if the patterns in the assemblage are similar or different to those found in blast-related combat trauma.
5. Formulation of guidance for the identification and differentiation of blast injury in skeletonised remains.

The five objectives will be met using morphological methods traditionally employed in biological anthropology while introducing the application of statistical methodology used in other disciplines to explore their potential for anthropology and trauma analysis. The first objective is met by examining the prevalence statistics published in clinical literature and compiling the data regarding trauma to the skeleton so that it may be applied to skeletonised remains. The second objective is met by employing multivariate statistics to undertake an exploratory examination of the data using cluster analysis and multiple correspondence analysis to identify patterns differentiating blast trauma from gunshot trauma. The third objective is met by employing probabilistic modelling, specifically binary logistic regression to predict the type of trauma based on the pattern of damage to specified body regions. Finally, the results of the analyses are compared with the clinical literature prevalence data to compare and contrast the similarities and differences between the patterns of injury in the studied samples and those published previously. This is all brought together to achieve the fifth objective and present guidance for the anthropologist based on the results of the thesis.

The thesis is divided into eight chapters. The second chapter examines the historical development of explosive material with the aim of understanding the course of the creation of various explosives, each phase progressing towards the materials familiar today. Throughout their development, the chemical and physical characteristics of explosives changed, impacting on the trauma seen in the human body. The third chapter addresses these chemical and physical characteristics and how these affect the trauma which is seen in both soft and hard tissues of the body. The patterns of injury seen in various contexts are presented to permit comparison with the data collected.

Chapter four introduces the samples which are analysed in the project. Their origin, composition and acquisition are described. Chapter five explains the methodology employed in the project whilst framing it in the theoretical tradition of inductive reasoning. The selection of statistical analyses is explained along with the procedures undertaken to analyse the samples using descriptive, cluster analysis, multiple correspondence analysis and binary logistic regression statistics.

Chapter 6 presents the results of the exploratory statistical analyses and probabilistic modelling. Comparison with the clinical literature data is made to identify similarities and differences within and between the samples. Chapter 7 explains the results from chapter 6 and frames these within the context of forensic and biological anthropology to permit identification of blast injury in large scale assemblages.

Finally the thesis is concluded with a retrospective of the aims and objectives and how these have been met. Future areas of research are discussed and the crucial importance of this work is discussed.

2. Historical background and introduction to the science of explosives

Understanding the historical development of explosives is vitally important as the changes to explosive materials and development over the years has impacted the resulting injuries which are seen in soft and hard tissues. Early explosives were of the incendiary type which causes very different injuries to modern explosives, primarily burns. Modern explosives injuries affect many biological systems at once; both soft and hard tissues as well as the nervous and autonomic systems (see section 3.4). The transition from early explosives to those which are familiar today shows an increase in the wounding power of these materials and thus makes it critical to gain an understanding of how these mechanisms came about alongside examining their chemistry, physics and biomechanical wounding potential.

Tracing the historical development of explosives is complicated and can be attributed to various sources. It is widely accepted that the path to the creation of modern day explosives began with the discovery and production of black powder, which in the form we are familiar with is generally regarded as having been developed by the Chinese in the 12th century A.D (Brown 2005). This development led to the creation of the explosive materials which are part of this study.

This chapter will explore the history of explosives, the developments in the science of explosives spurred on by the military and mining fields, as well as introducing the basic forms and uses of explosives. The next chapter will delve further into the science of explosives, including the physics, chemistry and biological effects of blast.

2.1. History of Explosives

Prior to the development of what we know to be black powder (see 2.3.1), other types of early "explosives" were documented in societies pre-dating those in China. These were more of the incendiary type rather than the explosive type. These did not produce the typical explosive chemical reaction which would make them detonate, as in high explosives. Instead these deflagrate or burn. One example of this is the Egyptian use of nitre on fires to produce a rapid burning reaction. This was then followed by the discovery that the inclusion of powdered resin or sulphur would in fact accelerate the reaction caused by the nitre. Other examples are documented mixtures of compounds which were chemically balanced similarly to those in gunpowder, creating a mixture of approximately 75% potassium nitrate, carbon and sulphur. These mixtures are known to have existed in the pre-Christian era (Morgan 1967; Partington 1999).

2.1.1. Greek fire

The most widely known precursor to black powder and modern explosives is Greek fire, whose origins and composition are disputed in various sources. Some sources attribute to it an origin in petroleum products (Morgan 1967; Partington 1999). Whilst others postulate that it was indeed a mixture of nitre, resin and pitch. Agreed upon however, was its intended use, documented as having been utilised in warfare as early as A.D. 650. Unlike conventional explosives, it is believed that Greek fire was merely used as an incendiary device to cause fiery destruction to enemy ships rather than an explosion as we would know it (Morgan 1967).

2.1.2. China

The Chinese are attributed as employing the first "purpose designed" explosives, which used black powder. Mention of this is made in a manuscript dating from 1040 A.D. and includes the description of items resembling explosive grenades and bomb type materials used in association with catapults, presumably for launching these at enemies (Zukas and Walters 2003). The development of a bamboo container sealed with clay and containing a fuse, permitted the conception of Roman candle type fireworks (Morgan 1967).

2.1.3. Roger Bacon

In Europe, Roger Bacon (1214-1294) is attributed with the introduction of gunpowder, publishing the formula in 1242 (Brown 2005). He experimented with various mixtures of the components of black powder, seemingly with the original aim to re-create Greek fire, which he did not successfully achieve. This is perhaps due to the fact that Greek fire may have been petroleum based rather than potassium nitrate and sulphur based as black powder is. Continuing on with his mixtures, he achieved accurate mixing of the correct components of black powder as well as the proper sequence of preparation. This mixture was also put into containers, effectively creating an explosive container which would be the precursor to modern explosives and weapons development and manufacture in Europe (Morgan 1967). These developments would begin the creation of all types of weapons including guns, cannons and modern bombs.

2.1.4. The 19th Century

It was not until the 1800's that the mass development of substances of an explosive nature really took off. During this era, black powder was used predominantly as a propellant for weapons with a small bore and for cannons. It had numerous disadvantages which included the production of lots of smoke. It also deteriorated rapidly when it became damp (Tooley 1971). Due to these disadvantages, development of different propellants was the priority in 19th century explosives improvement. As a result of this necessary development, Alfred Nobel developed a new propellant, still used in bullets and shells today, named ballistite. This composition is achieved by mixing glyceryl trinitrate with mineral jelly and guncotton. This mixture comes in various forms, such as slurry for easy pouring and heat curing for use in mining applications.

2.1.5. Early explosive ordnance

The early examples of explosive ordnance include the use of basic shells,. Shells were an outer metal casing filled with explosion material, the fuse and possibly additional material for fragmentation (Zajtchuk 1990). The late 19th century saw the advent of the use of anti-personnel munitions with the inclusion of lead shot in shells. Early grenades looked like pineapples to pre-determine the fragmentation pattern and were made of cast-iron or steel. These were thrown by hand (Zajtchuk 1990).

2.1.6. Mining

Although most popularly associated with warfare, the development of explosives in the 19th century was largely driven by industrial applications such as mining and railway construction. The use of black powder as an explosive in mining at the time was considered to be dangerous and ineffective (Akhavan 2004). A better explosive was required and this precipitated the creation of one of the most important explosives, nitroglycerine, whose manufacturing process was created and refined by the Nobel family (Akhavan 2004). The family encountered many setbacks which include the destruction of their factory along with the death of a member of the family as a result of experimentation with nitroglycerine. This exemplified the instability and sensitivity of nitroglycerine and its difficulty of transport. To counter this, it was mixed with clay and its sensitivity reduced. This is now known as ghur dynamite and was patented in 1867 (Akhavan 2004). Another type of dynamite was developed in the late 1800's, made by mixing the recently developed nitrocellulose with nitroglycerine. This composition led to the creation of blasting dynamite, gelatine dynamite and British cordite (Akhavan 2004).

2.1.7. Mercury fulminate

Black powder and the compounds subsequently created, such as cordite, are classified as low explosives and are generally used as propellants. High explosives, those which detonate, have a development history that can be traced back to the early 19th century. One of the first primary explosives developed during this time is mercury fulminate, whose discovery is attributed to Howard in 1800 (Tooley 1971). It had been previously developed in the 17th century and subsequently forgotten until Howard (Akhavan 2004). This explosive is a nitrous compound that is manufactured by nitration of nitric acid, mercury and ethanol and is used as a detonation charge due to its sensitivity to shock and ignition. However, this compound is prone to deterioration in heat and its instability requires it to be stored in water, as it is insoluble (Tooley 1971).

2.1.8. Nitration

In 1833, Braconnot used starch in the nitration process (See 2.3.3) (Tooley 1971; Akhavan 2004). Nitric ester was formed during this process and its resulting precipitate was used as a commercial explosive, however only on a small scale. Following this type of explosive was the development of Mannitol hexanitrate in 1847, which is also manufactured using the nitration process. This explosive was first prepared by Demonte and Menart and uses the sugar alcohol Mannitol ($C_6H_8(OH)_6$)combined with nitric acid and precipitated with sulphuric acid. Preparation of these chemicals yields an expensive explosive which is similar to pentaerythritol tetranitrate (PETN) but is less stable (Tooley 1971).

Trinitrotoluene

One of the most important explosives, especially to the history of military explosives use, is trinitrotoluene (TNT). It was first prepared by Wilbrand in 1863 but its production was mostly done in the mid to late 1890's by both the German and British forces (Tooley 1971; Akhavan 2004). Prior to the widespread use of TNT, trinitrophenol or picric acid were the most commonly used materials for the filling of shells in the military. Also used were Melinite (by the French) and Lyddite (by the British). The German army replaced the commonly used picric acid at the beginning of the 20th century with the American forces following suit shortly after (Akhavan 2004). TNT is widely considered to have been the primary explosive used during the First World War (Akhavan 2004) due to its low sensitivity and ease of use for filling shells in its liquid format (Tooley 1971). TNT is manufactured with toluene, which has to be extracted from coal tar, and during World War I, its stocks dwindled. Due to this deficiency of materials, picric acid was used instead and was mixed with ammonium nitrate, yielding ammonium picrate. Ammonium nitrate was also combined with TNT, to fight high costs and the lack of toluene, producing the explosive amatol (Tooley 1971; Akhavan 2004).

Ammonium Nitrate

The 19th century also saw the development of ammonium nitrate (Tooley 1971; Akhavan 2004), a familiar explosive which many of us have heard of due to its use in improvised bomb making, such as was used in the Oklahoma City bombing in the mid-1990 (Mallonee et al. 1996; Teague 2004; Glenshaw 2009). In the 19th century, Grindel and Robin (Akhavan 2004) proposed this substance as the replacement for potassium nitrate in the manufacturing of black powder. Subsequently Reise and Millon described the use of ammonium nitrate as an explosive, when they discovered that it could be combined with charcoal to cause an explosion. Experimentation with the combination of this material and substances such as sawdust, nitrobenzene and picric acid led to the use of this compound as an explosive. However, many accidental detonations occurred over the years, such as the destruction of various ships carrying loads of the chemicals (Akhavan 2004). Despite its apparent danger, this chemical composition is frequently used, especially in the mining industry, where is has been developed in various forms such as prill (which does not cake or become solid during storage), and is now mixed with fuel oils as is needed by the industry (Tooley 1971).

2.2. Military grade explosives

This section documents the development of explosives related to military use, another important driver behind innovation of these materials, along with the mining industry.

2.2.1. Late 1800's to the Great War (1914-1918)

Continuing on with the production of military grade explosives, Tetryl was used as a primer in anti-aircraft and high explosive shells. Its first production was in 1879 by Michler and Meyer. This type of explosive proved to be expensive and lacking in power and thus precipitated the production of a new type of explosive called pentaerythritol tetranitrate (PETN) by Tollens in 1891 (Tooley 1971). This high explosive is widely known today and its development advanced the creation of various explosives by combining PETN with a variety of substances (Akhavan 2004). It is manufactured by nitration, as with most high explosives, and is considered to be stable as well as a very powerful explosive. It is however very sensitive to friction and shock and precautions were developed for its storage, such as it being housed in a damp state and dried before use. Due to its high price it did not have widespread early military use. A common use of PETN is in combination with a plasticizer, which reduces the cost due to prolific manufacturing. When combined with plastics, PETN is termed plastic explosive (Tooley 1971).

2.2.2. World War II (1939-1945)

Following the First World War, during which was used Melinite, Lyddite, Picric Acid and finally TNT, more advancements were made in the development of explosives, particularly high explosives whose ultimate use was to fill shells during World War II. Discovered in 1899, Cyclonite is a preparation made from hexamine (hexamethylene tetranitramine) which is subjected to nitration with fuming nitric acid to become cyclotrimethylenetrinitramine. Cyclonite was patented in 1920 and used in bursting shells in World War II. In the United Kingdom, the material is known as RDX (Research Department Explosive) due to Woolwich Arsenal's research department involvement. Cyclonite is similar to PETN in its application for military purposes, but was found to have quicker brisance, reaching maximum explosive pressure in less time. This is likely to improve its effectiveness for certain tasks. As with other military-use explosives it is very sensitive to impact and can be combined with other materials to create new explosives. One example of this is Torpex, an explosive used for detonation underwater. This is composed of Cyclonite/RDX alongside TNT and aluminium powder. Ammonium nitrate can also be mixed with Cyclonite to produce a powerful explosive (Tooley 1971).

2.2.3. Post- World War II: HMX (cyclotetramethylene-tetranitramine)

A common, modern explosive is HMX, which is similar in chemical composition to Cyclonite. It is also a high explosive which detonates. It is also manufactured by the nitration process using hexamine dinitrate and acetic anhydride. The chemical nitration yields one of the most powerful high explosives known however, it is quite stable (Tooley 1971; Akhavan 2004). Despite the use of the common production technique of nitration, it is quite complex to manufacture and is thus produced for specialised applications (Tooley 1971; Cooper 1996; Cooper and Kurowski 1996; Akhavan 2004).

2.3. The manufacturing of explosives

The manufacturing of explosives can be separated into different processes based on the type of explosive being produced, classified as low or high explosives. The high explosives are those which detonate, whilst low explosives deflagrate and are typically used as propellants and are produced in a different fashion. The first method to examine is the manufacturing of black powder, the first low explosive created.

2.3.1. Black powder

Black powder is composed of three components, some of which vary slightly based upon the future use. Manufacturing of black powder has varied over time as well as with the intended final product's desired effect and is typically composed of 75% nitrate, 12.5% sulphur and 12.5% charcoal (Howard 2006). Each of these components has individual production methods. Sulphur is an element and obtained by either melting in a cast iron cauldron or sublimated. It was also mined later in history. Today, sulphur is a very inexpensive and plentiful by-product of the petroleum industry. Historically, the charcoal necessary for black powder production has been obtained in the form of carbonised wood. The last component is the nitrate, which composes 75% of the mixture in black powder. This component acts as the oxidizer. The nitrate used is typically potassium nitrate, however in both blasting and military explosives, sodium nitrate and ammonium nitrate are used to make black powder (Howard 2006).

Historically, these components were combined using a wheel mill. They were mixed when wet and put through the wheel mill where the sulphur would bind with the nitrate and the carbon (Cooper and Kurowski 1996). Since 1425, the ingredients are ground and pressed into a solid mass, a process called corning, and subsequently is broken into smaller grain. The corning process permits the creation of uniformly sized powder grains to control burning rate. Bigger grains result in slower burning, however the converse is also true.

Very fine, powdery grains also result in slower burning (Howard 2006). Following the corning procedure, the black powder is subjected to the glazing process, which involves tumbling the black powder in barrels. This results in the rounding of the grains, which reduces the physical degradation of the grains during transport and increases the density of the black powder. This increased density results in slower burning. If the black powder is glazed for an extended period of time, it results in 'hard glazing', which bring the nitrate component to the surface and aid in better combustion (Howard 2006). Finally, the black powder is dried to remove the water accumulated during production and then it is packed.

2.3.2. Propellants

Propellants are similar to explosives, on a chemical level, however they burn (deflagrate) as opposed to detonating. There are four categories of propellants: single base, double base, triple base and composite. Black powder is a composite propellant (Cooper and Kurowski 1996).

Single base propellants

Single base propellants are made from cellulose which is subjected to nitration. This process introduces nitric and sulphuric acids into the mixture and a chemical reaction produces nitrocellulose (Cooper and Kurowski 1996). Nitrocellulose decomposes at high temperatures and thusly needs to be combined with stabilisers. These stabilisers react to prevent further degradation by forming nitrates and nitrate esters. Commonly used for this purpose are diphenyamine, nitrodiphenylamine, mineral jelly and necrolin (Cooper and Kurowski 1996). The nitrocellulose is then processed into its various forms by dissolving it into acetone and extruding it through dies into pellets or grains. The nitrocellulose can also be pressed into various formats, including spheres, pellets, discs or sheets (Cooper and Kurowski 1996).

Double base propellants

Double base propellants predominantly use nitroglycerine. These are typically produced by combining two propellants in liquid form to then combine these with gelatine or plastic afterwards. The combination of the second propellant aids by chemically balancing the oxygen and producing a varied energy output and reaction temperature. Nitroglycerine is commonly used for this process and results in a material that can be processed and extruded without having to be dissolved in a solvent such as acetone (Cooper and Kurowski 1996).

Triple base propellants

Triple base propellants combine nitrocellulose and a reactive plasticizer such as nitroglycerine and nitroguanidine. This third component, as with the double base propellants, acts as an agent to regulate the energy and temperature output, along with gas and speed, of the propellant (Cooper and Kurowski 1996).

2.3.3. High explosives

These materials are the ones which are commonly known, such as TNT and PETN. These detonate rather than deflagrate. These are manufactured through the process of nitration and have resulted in various materials which are commonly used in military applications.

Nitration

High explosives are manufactured similarly to some of the propellants, predominantly using the chemical process called nitration. This process introduces a nitro group into an inorganic chemical compound. Typically, nitric and sulphuric acids are used. There are three types of nitration, demonstrated in Figure 2-1: Method of nitration based on the combination of the nitro group with either the carbon, oxygen or nitrogen atom (from

Akhavan 2004). which outlines nitration based on the combination of the nitro compound either a carbon atom, an oxygen atom or another nitrogen compound. These preparations yield the commercial and military.

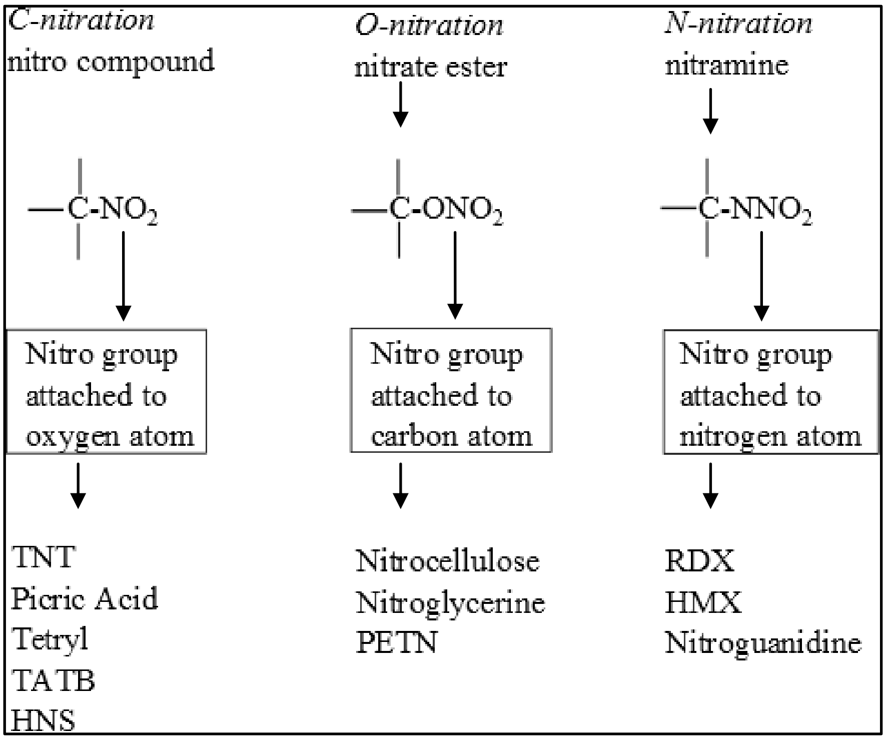

Figure 2-1: Method of nitration based on the combination of the nitro group with either the carbon, oxygen or nitrogen atom (from Akhavan 2004).

Typically, the first chemical is dissolved in sulphuric acid, which acts as the "inhibitor or moderator of the nitration" (Akhavan 2004). The resulting dissolution is then nitrated with the nitric acid. Nitration is performed as a chemical can't be explosive if it contains only one nitro group, it needs to have two or more for the compound to be an explosive (Tooley 1971).

Aliphatic and Aromatic Explosives

Two types of explosives are manufactured using nitration, aliphatic and aromatic explosives. The aromatic explosives contain a benzene ring and it is this benzene which is nitrated. One example of the aromatic explosive is Trinitrotoluene (TNT), which contains three nitro groups. This is made by singly substituting the hydrogen atom at the top of the benzene ring in trinitrobenzene. This is achieved through the typical process of nitration, executed in steps by mixing concentrated nitric acid and sulphuric acid. The hydrogen atom can be substituted on the benzene further to created multiply substituted trinitrobenzene, examples of which as trinitrocresol, tetranitroanilinine and triaminotrinitrobenzene (Cooper 1996; Cooper and Kurowski 1996).

Aliphatic explosives are more commonly known and were the first mass produced explosives. These do not contain a benzene ring. These explosives are very sensitive due to bubbles in the liquid form, which form produce vapour pressure points (Cooper and Kurowski 1996). One of the most common of the aliphatic explosives is nitroglycerine, which is manufactured by nitration of glycerine (a polyalcohol). The nitration affects the alcohol groups in the molecule. The liquid produced is stabilised with wood meal or absorbents, as in dynamite. It is often also combined with nitrocellulose to gelatinise the material for storage, preventing the settling of the explosive (Cooper and Kurowski 1996).

PETN: Pentaerythritol tetranitrate

PETN is a familiar aliphatic nitrate ester explosive that is used in the military, especially in detonating cords and mixed or cast explosives. This is also produced through a nitration process, one which requires a two-step process. Firstly, pentaerythritol is produced by mixing formaldehyde and calcium hydroxide. This aqueous solution is then subjected to nitration using nitric acid. PETN is removed from the liquid by being filtered, washed (with water) and neutralised with sodium carbonate. The last step requires it be recrystallised with acetone (Akhavan 2004).

RDX: Cyclomethylenetrinitramine

RDX is also manufactured using the nitration technique; however this is slightly more complicated and involves numerous chemical steps. Hexamethylenetetramine is mixed with nitric acid and subsequently warmed. The precipitate is removed and re-crystallised with acetone, as in PETN. Chemically, RDX goes through three intermediary compounds during this process, which are further affected by the nitration to finally yield RDX. This is the simplest process and others do exist. These are fairly similar in technique but use differing chemicals to achieve the same end (Akhavan 2004).

2.3.4. Inorganic compounds

Inorganic compounds can also be used as explosives. Their molecules do not have a carbon skeleton and are manufactured by the different methods than organic compound explosives. These involve the combination of fuel and oxidizer, typically ammonium nitrate. This is used extensively as a fertilizer, in its pure form, as it is difficult to initiate. When mixed with fuel, typically fuel oil, it is a very inexpensive and plentiful explosive which is used predominantly in the blasting industry (Cooper 1996; Cooper and Kurowski 1996; Akhavan 2004). Fulminates and azides, such as mercury fulminate and the hydrozoic acid salt lead azide, are also examples of inorganic compounds which are used as primary and initiating explosives in the blasting industry (Cooper 1996; Cooper and Kurowski 1996; Akhavan 2004).

2.4. Forms of explosives

Explosives are manufactured in various forms. These are often a mix of pure compounds with others to “change or alter the mechanical properties, as well as some of the thermal, output, or sensitivity properties” (Cooper and Kurowski 1996). Two very common examples of these preparations are those of dynamite and blasting gelatine. Dynamite is a combination of nitroglyerine, nitroglycerine and nitrocellulose or both in addition to ammonium nitrate. In standard dynamite, nitroglycerine in liquid form is mixed with wood meal or another absorbent material. This has the result of suppressing the nitroglycerine’s high sensitivity and improving its resistance to initiation by shock or impact.

When producing explosives, these can be manufactured in different forms which serve different purposes. These can be produced in the form of pressings, castings, plastic bonding, putties, rubber, extrusions, slurries and emulsions. A pressing requires that the explosive, which is in powdered or crystal form, is combined with additive to facilitate its production. This type of material can be made with a constant volume or constant force press to create pellets of the explosive. These can also be combined with chemical taggants for identification purposes. Casting is used to mix TNT with "higher melting crystalline explosives" (Cooper and Kurowski 1996) to alter the negative oxygen balance of TNT. This is adjusted by selecting the crystalline explosives to have a positive oxygen balance.

2.4.1. Plastic bonding

Explosives may also be plastic bonded. This is accomplished during the explosive's manufacturing process by combining it with polymer or plastic binders so that it coats the explosive during the precipitation phase of production. These then form pressing beads, which are created using die or isostatic pressing. These are then subjected to high pressure (between ten and twenty thousand pound per square inch) to produce pellets (Cooper 1996; Cooper and Kurowski 1996).

2.4.2. Plasticised and rubberised compounds

Three types of well known explosives are the American C-4 (Composition C 4), the United Kingdom's P4, and Semtex, invented in former Czechoslovakia. These types of explosives are putties, manufactured by mixing RDX in powdered form with plasticisers. These are then formed by hand, usually into bars, and hold their shape following the moulding. Semtex is slightly more complicated and involves the mixture of both RDX and PETN as its explosive composition. These two explosives are also combined with rubber polymers and plasticisers to create rubberized explosives. This mixture is extruded in rubbery gasket-like sheets, known by the industry names of Detasheet and Primasheet. These are used in detonators. Extrusions can also be manufactured with RDX or PETN by mixing with silicone rubber resin, in a ratio of 80% explosive and 20% resin. This is extruded and heated to create a rubber like material (Cooper 1996; Cooper and Kurowski 1996).

2.4.3. Slurries and Emulsions

Slurries and emulsions are also an important preparation of explosives, used predominantly in commercial blasting. The slurry technique was introduced in the late 1950’s and can be produced in large quantities using a solution of ammonium nitrate which has been thickened (Cooper and Kurowski 1996) and aluminium powder as the fuel. These types of mixtures are known as ANFO (ammonium nitrate fuel oil) explosives and insensitive to initiation. This problem is overcome by incorporating PETN or TNT, in powdered form, to the ANFO mixture. The mixture is thickened and can then be packed into cartridges (for sensitive slurries that have been gelled) or can be pumped directly into holes at blasting site, especially useful in the mining industry. Emulsions are the opposite of slurries. In emulsions, it is the oxidizer, ammonium nitrate, which is introduced into the oil matrix. Following this glass or plastic microballoons are also introduced to emulsions. These are used to adjust the detonation properties and sensitivity of the mixture and reduce the potential problems caused by the introduction of water into the compound (Cooper 1996; Cooper and Kurowski 1996).

2.5. Use of Explosives

Explosives can be found in a variety of situations, some more common and conventional than others. These are used in various industries, which are described subsequently, demonstrating the prevalence of explosive materials in the daily world.

2.5.1. Mining and gunpowder

Their first commercial application was developed for the mining industry (Tooley 1971) in the form of gunpowder. Prior to the use of gunpowder in mining, various techniques were employed which included fire-setting and lime-breaking. Fire-setting worked on the principle of heating up the rock to be broken with fire and then putting cold water on it, inducing thermal shock.. This technique was used by Hannibal during his journey through the Alps. Up until the 18th century, this technique was still employed (Brown 2005). Lime-breaking was also employed and functioned on the basis of a chemical reaction. Water was combined with quick-lime in holes bored into the rock. The heat of the chemical reaction causes steam and pressure to build up, subsequently breaking the rock apart (Brown 2005).

Gunpowder use in mining began in the 17th century in Hungary, employed by Tyrolean mining engineer Caspar Weindl. This method then spread to Germany and entered England in 1638 where it was brought to the Ecton copper mines by Central European miners (Brown 2005). The history of gunpowder can be examined in three separate phases. Its use before 1831 represents a laborious as well as dangerous process due to the methods of drilling and the lack of safe ignition methods. In 1831, the safety was introduced into use in a Cornwall mine. This consisted of a rope with a gunpowder centre that had a constant burning time. Despite a high price, this method was readily adopted and a decrease in the number of mining accidents was noted. The late 19th century phase of gunpowder witnessed the introduction of a variety of modifications to gunpowder with the purpose of improving the efficiency and safety of the methods used in mining industry. This was especially prevalent in the coal mining industry, which was notoriously dangerous and the single largest consumer of explosives (Tooley 1971; Brown 2005). Gunpowder was mixed with cooling agents, such as salts, borax and sodium bicarbonate to attempt to make the material safer for use. In 1914, Belgian chemist Lemaire introduced sheathed explosives, which surrounded the explosive with an inert cooling agent (sodium bicarbonate). This practice reached England in 1934 (Tooley 1971). Equal-to-sheathed explosives were then introduced, which mixed the coolant directly into the formulation, quenching the explosive flame. Salt and ammonium nitrate are utilised in this process (Tooley 1971).

2.5.2. Civil Engineering and Blasting Techniques

A concurrent and important phase of explosives use was the proliferation of blasting techniques for civil engineering. Gunpowder was first used in this context for the construction of the Languedoc Canal in France (Canal Du Midi) in 1681. In England during the mid-1700, this application was employed for the construction of canals for the transport of mined coal. Following these developments in, the civil engineering branch of explosives use expanded to the development of the railways which often required tunnels and deep cutting (Brown 2005).

2.5.3. Propellants, pyrotechnics, blasting caps and detonation cord

Explosives are also used as propellants in a variety of mechanical situations. The propellants have found use in creating the mechanical sequence in pistons (as in cars petrol and gas engines) and the production of the gases needed for ballistic propulsion in guns. These also find use in rocket propulsion as well (Morgan 1967; Tooley 1971; Cooper and Kurowski 1996; Brown 2005). Pyrotechnics are also a common use for explosive materials. These are used in preparations to create heat, light, smoke, delays, and the sounds traditionally used in fireworks (Cooper 1996; Cooper and Kurowski 1996). Explosives are also an important component of blasting caps utilised as initiating explosives. Mercury fulminate was an important early component of the first generation of blasting caps and primer for arms (Cooper and Kurowski 1996). Another related use is the deflagration and detonation cord that are used as delays or transfer lines to the main charges. A commonly used substance is PETN (Cooper and Kurowski 1996). In jet engines, explosives are used in the starter cartridges (Tooley 1971; Cooper and Kurowski 1996).

2.5.4. Commercial Use of Explosives

Commercially, explosives are employed for a variety of uses. The most notable use is ammonium nitrate. This, on its own, is used as fertiliser and is found widespread in farms. Combined with fuel oil however, it becomes explosive and is used in commercial mining, mixed on site from the two separate materials (Tooley 1971).

Interestingly, explosives are also used in the commercial shaping and engraving of metal. This is accomplished by placing an explosive charge above a sheet of metal, which is subsequently placed above a mould. The use of stencils is also employed in this industry as well. Metal cladding can also be fabricated using explosives. Using explosives, a sheet of cladding is welded to the surface below. Reinforcing filaments can also be placed into metal by sandwiching them between two sheets of metal and sheet explosive, which is detonated (Tooley 1971).

Traditionally, explosives are used in demolition work, which most of us are familiar with. Along the same lines, they are also used in scrap metal breakdown, used to render especially large pieces to a manageable size for melting down. Both geological surveying and fire fighting use explosives in an unconventional way. In geological testing, these are used to map features through sound waves. Fire fighting employs the physics and chemistry of explosives to put out fires in oil wells. They are used on the principle that when detonated, the chemical process of the explosion uses up the oxygen in the surrounding area, thereby removing one of the important components of a fire and putting it out (Morgan 1967).

2.5.5. Military application: Shaped explosive charges

A revolutionary technique in military explosives use is the shaped explosive charge. This is based on the Munroe effect, discovered in 1888. The Munroe effect involves the manufacturing of the explosive charge with a hole or void, causing a concentration of the explosive blast, effectively a jet. This was expanded upon during World War I and World War II, resulting in the bazooka and PIAT (Projector Infantry Anti-Tank) weapons, used to penetrate armour plating on tanks (Tooley 1971). This type of technology has also seen commercial use, used for perforation of oil wells and the tapping of open hearth steel furnaces along with underwater telegraph wire cutting (Tooley 1971), demonstrating the importance of the discovery and application of the Munroe effect for a variety of purposes.

2.5.6. Relevance to the research

The evolution of explosives has affected the types of injuries seen in the body with the creation of explosives designed to maim rather than kill instantly. Therefore it is important to understand the historical development and how this can affect the types of injuries seen. Comparing World War One mortar injuries to those seen in improvised explosive devices will necessarily yield a different pattern, due to differences in the construction. Additionally, this will change based on the explosive material used. For example gunpowder is a much less powerful explosive than PETN, a high explosive material. As such the injuring force is different and this affects the biodynamic interaction.

Understanding the historical development of explosive materials and the way they are made into the different preparations impacts the understanding of the biodynamic processes which injure the body. Low explosives and high explosives injure differently, for example a high explosive will have more impact on the soft tissues of the body due to the blast wave component of these explosions. This also applies to the evolution of weapons over time. World War One saw the predominant use of mortar rounds, which injure through the shrapnel component which is created by the breaking of the casing. Improvised explosive devices are often filled with materials to maim, such as nails or ball bearings. Anti-vehicle explosives, such PIAT anti-tank weapons contain a high explosive material which affects the interior of the vehicle with the blast wave as well as shrapnel components. As such, examining skeletonised remains which have been injured by modern weapons will necessitate the knowledge of the effect of the blast wave on the body (such as traumatic amputation) and not solely the effect of irregular casing shrapnel.

Much of the information gathered from clinical literature deals with previous conflict with which we can access data and can correlate specific types of injuries with the characteristics of the explosive material used and its container. Without comprehension of the range of historical and modern weapons and their effects, compiling information which can be used in anthropological investigation would be difficult. When faced with identifying injuries from a specific type of explosive, it is crucial to know how previous and current weapons interact with the body, making it possible to evaluate the injuries based on their development and their biomechanical interaction with the body. Chapter 3 examines these interactions, varied based on the type of explosive.

3. Project background: chemistry, physics and biomechanical response to explosives

It is critical to understand blast mechanics as the combination of physics, chemistry and biological response to blast determines the patterns seen in the human body. This chapter introduces the necessary concepts to understand the mechanism involved in trauma from blast. This includes an exploration of the chemistry and physics of explosions, which can dictate the type of trauma seen in the human body. The second section explores the patterns of injury which are described in the clinical literature and those applicable to specific blast contexts such as terrorist incidents, suicide bombings and combat injury. This situates the research within the current knowledge regarding blast injury.

Lastly, this chapter introduces the statistical methods and concepts which have been previously used in anthropology, particularly in trauma analysis and explores the applications and potential of the specific methods chosen for this thesis.

All terms employed regarding the physics, chemistry, biomechanics and medical description related to blast injury are derived from standard conventions and nomenclature in clinical literature as well as chemistry and physics.

3.1. Physical versus chemical explosions

Studying the chemical and physical properties of explosives is an important step in understanding blast injury. Chemical properties of explosives determine their type classification and the effects on the surrounding environment during a detonation or deflagration. There are three ways of classifying explosives and the explosions they cause: physical, chemical and atomic.

3.1.1. Physical explosions

A physical explosion is defined as occurring when a substance undergoes rapid physical deformation, which happens during compression as well (Akhavan 2004). The energy accompanying the physical explosion becomes kinetic (energy due to motion) and is accompanied by a shockwave in the surrounding space (Akhavan 2004). An example of this is the explosion of oxygen tanks used in scuba diving, which can explode due to a point of weakness in the outer tank, permitting an explosion release of the gas from the inside. This is due to the difference in pressure, with the pressure being higher inside than outside the cylinder.

3.1.2. Chemical explosions

Chemical explosions vary from physical explosions in the sense that these are the result of a change of chemical state in a rapid period (Akhavan 2004). This is also accompanied by a large generation of heat and gasses. This is caused by a rapid exothermic reaction, which occurs so quickly that the gases do not expand instantaneously but remain in the container, taking the place of the explosive charge (Akhavan 2004). In this small space, the pressure is so great that when it escapes, this results in a blast wave, capable of causing damage to objects at a distance (Akhavan 2004).

For this piece of research, chemical explosions are of main interest and atomic explosions are outside the remit of the work. Chemical explosions are the focus of this research due to the availability of data for the project. Clinical literature predominantly deals with this type of explosion due to the wealth of information contributed by research in war time contexts, where most medical research is developed.

3.2. Types of explosives: high/low and primary/secondary explosives

Explosives are substances which can undergo a “rapid chemical reaction evolving a large amount of heat and so exerting a high pressure on its surroundings” (Agrewal and Hodgson 2007). These products undergo their chemical reaction without outside involvement, such as the external reactant oxygen (Meyer et al. 2007). The chemical reaction is initiated by various means which can include mechanical (impact or friction), heat (flame, spark or heat) or shock (energy pulse, charge) methods (Agrewal and Hodgson 2007; Meyer et al. 2007). Explosive materials can be subdivided in two ways, low and high explosives or primary and secondary explosives based on various chemical properties, such as their sensitivity and ease of chemical reaction. Patterns of injury are affected by the type of explosive material used, with high explosives causing more physical damage due to its increased power over low explosives. Low explosives are of the burning type and do not cause the same amount of damage, reducing the injuring potential of the materials.

3.2.1. High and Low Explosives

Low explosives are classified due to the deflagration (burning) of the chemical, on the surface. These are also known as propellants (Agrewal and Hodgson 2007). There are exceptions and some of these materials may indeed detonate, but require confinement and an explosive shock to commence the reaction (Agrewal and Hodgson 2007). Substances classified as low explosives include smokeless powder and gunpowder(Morgan 1967; Tooley 1971; Cooper 1996; Cooper and Kurowski 1996; Zukas and Walters 2003; Agrewal and Hodgson 2007; Meyer et al. 2007).

High explosives are classified based on their ability to detonate, without confinement. These substances are subjected to a self-sustaining reaction, the chemical reaction being propagated by a high-pressure shockwave through the material (Agrewal and Hodgson 2007). High explosives include familiar compounds such as PETN, HMX, RDX and nitroglycerine.

3.2.2. Primary and secondary explosives

Primary and secondary explosives are classified based on the sensitivity of the materials to mechanical and thermal stimuli (Agrewal and Hodgson 2007). Explosive materials can be classified in two categories, primary and secondary.

Primary explosives are used as initiators due to their increased sensitivity to mechanical stimulus. These will explode with minimal effort and will also explode when subjected to heat (Agrewal and Hodgson 2007). These materials are used as initiators for larger explosive charges which require stimuli to undergo detonation. An example of primary explosives is nitroglycerine. Secondary explosives, such as RDX, are more stable and used as the main explosive charge combined with a primary explosive for initiation.

3.3. Physics of explosives

An explosion is defined by its rapid generation and violent escape of gas created by the chemical reaction of explosive material (N.F.P.A 2004). This is a gas dynamic reaction that includes rapid conversion of a solid or liquid material accompanied by energy release along with an over-pressurised shockwave travelling at speeds quicker than the speed of sound (Hull et al. 1994; Wightman and Gladish 2001; N.F.P.A 2004; Ciraulo and Frykberg 2006). The explosion follows two different pathways dependent upon the type of explosive material used: deflagrating or detonating explosive (Beveridge 1998). An explosion involving a deflagrating explosive material is a self-sustaining reaction due to its heat. This heat causes an increase in reaction that perpetuates itself. This heat may also be provided by the shockwave. In this type of explosion, reacted materials travel away from unreacted explosive material (Beveridge 1998).

Conversely, detonating explosions behave differently. The products of its chemical reaction travel towards the undetonated explosive at high speed and with high pressure and temperature. Following this is a chemical reaction zone completing the explosion (Beveridge 1998).

3.3.1. Positive and negative pressure phases

To understand the biodynamics of primary blast injury, a basic understanding of blast physics is required. The injuring blast wave is caused by the expansion of gasses generated by the explosion. This acts like a wave, propagating out from the centre of the blast (Cooper and Kurowski 1996). This is called the shock wave. Three components, all important injuring factors in a blast, form the shock wave. The first is the high positive pressure phase occurring immediately after the blast, which is the longest portion of a shock wave and causes a rise in the ambient air pressure. Following the passing positive pressure, a negative pressure phase occurs, which is actually below ambient atmospheric pressure. This can be represented graphically as an idealised Friedlander curve as seen in Figure 3-1, where the overpressure which accompanies the blast is seen early on the time axis, reaching its peak rapidly. Until the overpressure drops to atmospheric pressure, this is referred to as the positive phase. Pressure dropping below atmospheric pressure represents the negative pressure phase and with time this pressure phase returns to normal atmospheric pressure. This is illustrated in Figure 3-1, which graphically illustrates the positive and negative pressure phases in comparison to the stable atmospheric pressure (dashed line).

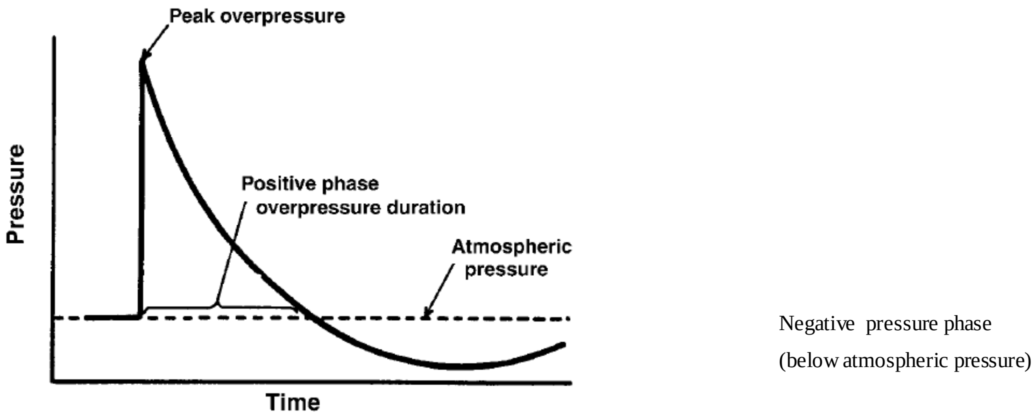

Figure 3-1 : Positive and negative pressure phases (from Horrocks and Brett 2000)

Accompanying the positive and negative pressure phases is the blast wind, a mass movement of air caused by the explosion. This is a dynamic pressure that moves more slowly than the blast wave (combination of positive and negative phases of the explosion). The expansion of gas accelerates molecules of air into a high speed wind (Boffard and MacFarlane 1993). This may also be caused by a countermovement of air filling the vacuum created by the negative phase. Once blast wind resolves, a return to ambient air pressure occurs (Mellor 1992; Boffard and MacFarlane 1993; Mallonee et al. 1996; Covey 2002). The blast wind is capable of propelling objects and can be as damaging as the original explosion itself.

3.3.2. Open, Semi-Confined and Enclosed Explosions

Explosions occur in a variety of locations, which can be open space, semi-confined and enclosed (such as vehicles). The physics of a blast is affected greatly by the containment of the area in which an explosion occurs. In an open air explosion, overpressure and its accompanying negative phase and blast wind quickly dissipate. In a confined space, an additive effect occurs due to reflection of blast waves on objects, walls, floor and ceilings (Boffard and MacFarlane 1993; DePalma et al. 2005; Ciraulo and Frykberg 2006). A reversal of wind back to the centre of the explosion can also occur and will result in lower than normal pressure and increased injuries (Depalma *et al.* 2005) due to the complex waves and their sustained duration (Chaloner 2005). This will impact any conclusions made during the research as the environment in which a blast takes place must be taken into consideration.

3.4. Biological response to explosion and clinical patterns of injury

Blast injury can be defined as specific injuries to the human body caused by the blast's physical properties and penetrating missiles set in motion by the explosion itself. These injuries can have as a source either the shock wave associated with the explosion or the movement of air (blast winds) by the explosion (Haywood and Skinner 1990; Ciraulo and Frykberg 2006). Blast injury represents a variety of complex injuries. Bombings, especially suicide bombings, are situations involving high complexity due to the random nature of this type of attack, variability in the injury patterns, high concentration of soft tissue damage and prevalence of injury affecting multiple organ systems (such as vascular, skeletal, neurological), termed multisystem injury (Neuhaus et al. 2006). The complexity and intensity of blast injury is affected by various factors as are the physics of the explosion itself. The largest part of blast injury is penetrating injury, which represents a higher energy transfer on soft and hard tissues. The amount of energy transfer determines the degree of damage endured by the tissues. The kinetic energy of fragments creating penetrating injuries is dependent on their mass and velocity and will transfer to the tissues it impacts upon (Coupland 1994; Hull 1996). The tissues subjected to these missiles will impart a degree of retardation based on their area, elasticity and density. Bone will behave differently when put under missile stresses due to its mechanical properties including high density, permitting an energy transfer with less destruction than soft tissue (Hull 1996). However, due to irregularly shaped missiles characteristic of explosive blasts (versus bullets), the ballistic instability of such materials means that they will deposit more of their kinetic energy much faster and with greater tissue destruction than bullets striking a human target (Cooper *et al.* 1983). It is because of these varying biodynamic factors that missiles created by an explosion will behave differently than bullets and consequently impart differing injury patterns. As demonstrated various fragments behave differently and are impacted by their shape, velocity as well clothing and the tissues it must travel through (Bowyer 1996; Bowyer et al. 1996). These factors impact the depth of the fragments penetration as well as the size of the temporary cavity left behind.

The position of the body relative to the blast is also an important factor to consider when examining blast injury. The severity of the impact and the injuries sustained are much higher when standing perpendicular to the blast as opposed to horizontally (Ciraulo and Frykberg 2006). Proximity is also the single most important determinant for the severity of blast injury and is responsible for the high incidence of death to those standing close to the blast(Ad-El et al. 2006; Mayo and Kluger 2006; Neuhaus et al. 2006). Further away from the epicentre of the blast, cause of death is more likely to be attributed to the intense overpressure created by the blast, as opposed to the detonation or deflagration of the explosive material itself (Mayo and Kluger 2006). Also, more penetrating type injuries are encountered, from the material being detonated in the bomb (casings) or objects and structures being destroyed around victims. Blast loading, which is the force on a structure produced by the combination of the weight and standoff distance of a blast charge, is also influential in the types and severity of the injuries sustained during an explosion. Mellor (1992) demonstrated in a study of Irish servicemen that a higher blast loading was associated with an increase in blast lung injury and a smaller blast load correlated with a larger number of head injuries. The further a victim is away from the central blast, the less likely they are to be injured due to the drop off in blast loading related to stand-off distance. Additionally, lateral movement has no impact on blast loading, only distance from the epicentre will impact the amount of force the blast wave has as it goes through tissues (Lockhart et al. 2011).This illustrates the importance of knowing the context of the incident as the types of injuries are dictated by many factors which vary the situation. The more information anthropologists can obtain, the better they will be prepared to look for patterns of injury that can be identified in the assemblage of skeletons. This gap in knowledge is extremely important to address as the number of blast events increases in a variety of situations within which anthropologists may be invited to contribute (such as terrorism, war and criminal investigations).

Blast injury has been historically subdivided into four categories based on the biodynamics of the injuries and the blast physics causing the injuries (Zuckerman 1940 in Chaloner, 2005; Zafar *et al.* 2005). The spectrum of blast injury is typically divided into primary, secondary, tertiary and quaternary blast injury. Each injury pattern includes a predominant type of injuries which are associated with specific blast mechanics, such as the blast wave. Being familiar with aspects of the situations context can aid in determining what types of injuries one can expect, particularly if location information is available for victims. The injury patterns identified are a general assessment of what to expect when examining blast victims but can nonetheless be useful in correlating injuries and context. Anthropological investigation can benefit from this and this piece of research examines the applicability of the patterns of injury from the medical literature to an anthropological assemblage to determine suitability of the appropriation of these for the biological and forensic anthropology.

3.4.1. **Primary blast injury**

Primary blast injury is the result of the shock wave and its accompanying components, such as the positive and negative pressure. It is estimated that 86% of fatal blast injuries are of this type (Wightman and Gladish 2001). The resulting primary blast injuries are due to the effect of the blast wave passing directly through the body. The effect of the blast wave is most profound at the air- and fluid- filled interfaces in the body, such as the lung (Chaloner 2005; DePalma et al. 2005; Ciraulo and Frykberg 2006). This causes blast lung injury, which is a difference in the pressure between the alveoli of the lungs and the liquid-filled capillaries, caused by the overpressure of the positive pressure phase. This pressure disrupts the barrier between the two and causes bleeding into the alveoli (Mellor 1992; Boffard and MacFarlane 1993; Langworthy et al. 2004a; Chaloner 2005; Zafar et al. 2005; Ciraulo and Frykberg 2006).

The lung is not the only organ to be affected by primary blast injury. The eardrum is also particularly susceptible to injury caused by the blast wave (Covey 2002; Chaloner 2005; Ciraulo and Frykberg 2006). The presence of eardrum perforation in victims has long been stated as an indicator of the presence of blast lung injury and poor prognosis due to the low pressure threshold at which this injury occurs (Ciraulo and Frykberg 2006). This notion has been challenged in a large study examining the effects of blast on victims of civilian terrorism and demonstrated that there was no correlation between blast lung injury and ear drum perforation (Leibovici et al. 1999).

Other injuries are also caused by the blast wave, and categorised as primary blast injury. This includes spalling (fragments of soft tissue ejecting from an organ) at the interface of two media of different densities, causing turbulence and cavitation. This is accompanied by spalled particles of the less dense medium travelling into the denser medium (Stapczynski 1982; Boffard and MacFarlane 1993). Implosion can also be a consequence of the blast wave and occurs when an air bubble rapidly contracts following the extreme drop in overpressure accompanied with the negative phase of the blast. The bubble subsequently expands rapidly, causing its own explosion in confined spaces and can lead to the passage of air into various tissues and vessels. Inertia, which is also a result of the blast wind interacting on the human body, causes the movement of the viscera within the body cavities and can cause contusions and tears (Boffard and MacFarlane 1993).

Typically the description of primary blast injury examines the soft tissue consequences of the blast wave. The current focus in the clinical literature is on the effects and sequelae of traumatic brain injury, most often caused by the primary blast and the accompanying wave. Despite this, there have been links between skeletal injuries and the blast wave which could potentially be utilised in the examination of blast injury in anthropological investigation. A further examination of the potential traumatic skeletal injuries from the blast wave is made in a subsequent section, addressing the injuries found in the sinuses, the possibility of bone fractures from overpressure and the mechanism of traumatic amputation (see 3.6).

3.4.2. Secondary blast injury

Secondary blast injury is the most common injury mechanism encountered in both fatalities and survivors (Ciraulo and Frykberg 2006). It is the leading cause of mortality and morbidity in terrorist bombings in the Middle East (Langworthy et al. 2004b; Ashkenazi et al. 2005) and around the world (Mayo and Kluger 2006). It is characterised by penetrating injury caused by fragment implantation in the tissues. The projectiles, which are often materials that have been added to the explosive devices (Kluger 2003; Ciraulo and Frykberg 2006; Mayo and Kluger 2006; Weil et al. 2007) are propelled by the blast wave or the negative wave pulling materials back towards the epicentre of the blast (Ciraulo and Frykberg 2006) The projectiles can travel with both high and low velocity (up to 823m/s) and can create blunt or penetrating ballistic trauma (Boffard and MacFarlane 1993; Wightman and Gladish 2001; Kluger 2003; DeWitte and Tracy 2005). Injury patterns created by penetrating fragments reflect the shape and velocity of the fragments and are varied based on their resemblance to ballistic materials (i.e. ball bearings) or irregularly shaped projectile (i.e. container pieces) (Kluger 2003). Section 3.7 expands on this with an examination of specific types of injury and the differences between ballistics wounds (such as gunshot wounds) and those from blast fragments. The patterns of injury which differentiate both again indicate the possibility of identification of blast injury from the skeleton if the anthropologist is familiar with these.

3.4.3. **Tertiary blast injury**

The third blast injury category, tertiary blast injury, describes the phenomenon of body displacement associated with explosive blasts. It involves the deceleration of the body and impact upon the ground, walls or objects by the human body or body parts (Mellor 1992; Chaloner 2005; DePalma et al. 2005; DeWitte and Tracy 2005; Ciraulo and Frykberg 2006). This movement is caused by an acceleration of the body by the blast winds and the expanding gasses of the violent explosion (Boffard and Macfarlane 1993; Wightman and Gladish 2001). Blast injury of this category is the second most common trauma in survivors, following secondary blast injury (Ciraulo and Frykberg 2006) and involves closed injuries, blunt abdominal and chest trauma, extremity fracture and traumatic amputation to exposed limbs impacting surfaces (Boffard and Macfarlane 1993; Chaloner 2005; Ciraulo and Frykberg 2006; Depalma *et al.* 2005). The mechanism of traumatic amputation has been disputed by various studies. These have concluded, through use mathematical modelling and experimentation, that traumatic amputation is associated with the blast wave (primary blast) and is a fracturing of the limb shaft rather than a severing of limbs at the joints due to tertiary mechanisms (Hull 1992; Hull et al. 1994; Hull and Cooper 1996). This will be addressed further on in Section 3.6.

These types of injuries lead to identifiable trauma on the skeleton resembling blunt trauma. The issue at hand is the possibility of differentiating other causes of blunt trauma from that of blast trauma. Due to the characteristics of blunt trauma there may differences drastic enough to permit a differential diagnosis with certainty. Examination of specific cases of tertiary blast injury in which the full context is known could permit a study of differentiating factors but would be out of the scope of this research project and remains an avenue for further work.

3.4.4. Quaternary and quinary blast injury

This category of blast injuries includes miscellaneous injuries that do not fit into the previous three categories of injuries. This is where burn injuries are classified. Flash burns from the intense but short heat of explosion are considered quaternary blast injuries (Mellor 1992; Horrocks 2001; DePalma et al. 2005; Ciraulo and Frykberg 2006; Mayo and Kluger 2006) The heat from the explosion can be up to three thousand degrees centigrade but does not last long and quickly dissipates with time and increasing distance from the source (Mellor 1992; Boffard and MacFarlane 1993). Explosive materials are now used in incendiary devices combined with elements such as napalm with powdered aluminium. This increases burning time, severity and prevalence of quaternary blast injury (DePalma et al. 2005).

The possibility of chemically and radiologically induced injury, such as methaemoglobinaemia, is classified as quinary blast injury in the literature (Ciraulo and Frykberg 2006). This condition refers to poisoning by dinitrobenzene, a component of wartime munitions, causing an oxygen binding and carrying incapability in the blood (Horrocks and Brett 2000).

Both quaternary and quinary blast injury are of lesser relevance to biological anthropology as soft tissue injury would be the predominant result of the mechanisms at action. As such, little focus can be placed on these for the current research project.

3.5. Injury patterns in previous research

Examination of the previous research to establish the current state of knowledge on patterns of injury is necessary to establish focus and expansion. The study employs the clinical literature to build an examination of the patterns which can be of use and contribute to knowledge in anthropology, as this type of trauma is not extensively studied in the literature.

Many factors influence the patterns of injury in different scenarios, such as the composition and delivery method of the explosives, the stand-off distance and any intervening protective barriers or environmental hazards (C.D.C 2003). These factors make it difficult to anticipate all possible injuries and consequently, the patterns described in the various studies undertaken describe general areas of injury. However, this information is still valuable and will aid in establishing patterns of skeletal injury which are relevant to anthropological investigation through the generalisation of patterns that can potentially be further refined through subsequent research.

The results of the clinical studies are examined below.

3.5.1. Terrorist incident studies

In terrorist incidents, defined for the purposes of this piece of research as acts of violence using explosives which target non-combatants, general conclusions have been drawn which are applicable to the large scope of these types of events. They represent characteristics applicable to a variety of situations which can inform anthropologists during investigation. In the context of terrorist bombings, injuries occur predominantly to the head, neck and peripheries and are due to the lack of protective effect of clothing in these areas (Hadden et al. 1978; Boffard and MacFarlane 1993). Hayda and colleagues (2004) state that 85% of injuries are to the extremities and include traumatic amputation, fractures and crush injury. Injuries to the chest and abdomen such as blast lung injury are uncommon, but are associated with high mortality due to the severe disruption of air-filled biological systems. Primary blast lung injury is not often encountered in survivors of terrorist bombings (Hadden et al. 1978) due to the severity of this type of trauma but is encountered more frequently in those taking place in confined spaces (Brooks et al. 2011).

Those who survive terrorist bombings predominantly have musculoskeletal injuries such as fractures, sprains and strains (Frykberg and Tepas 1988; Neuhaus et al. 2006) as well as superficial soft tissue injuries such as lacerations. Victims succumbing to injuries caused by terrorist attacks are affected by multiple severe trauma involving amputation, head injuries, penetrating thoracic and abdominal injuries (DePalma et al. 2005) The distribution of these injuries is shown in Figure 3-2, which compiles frequencies from studies on terrorist incidents (involving targeting of non-combatants) and combat incidents.

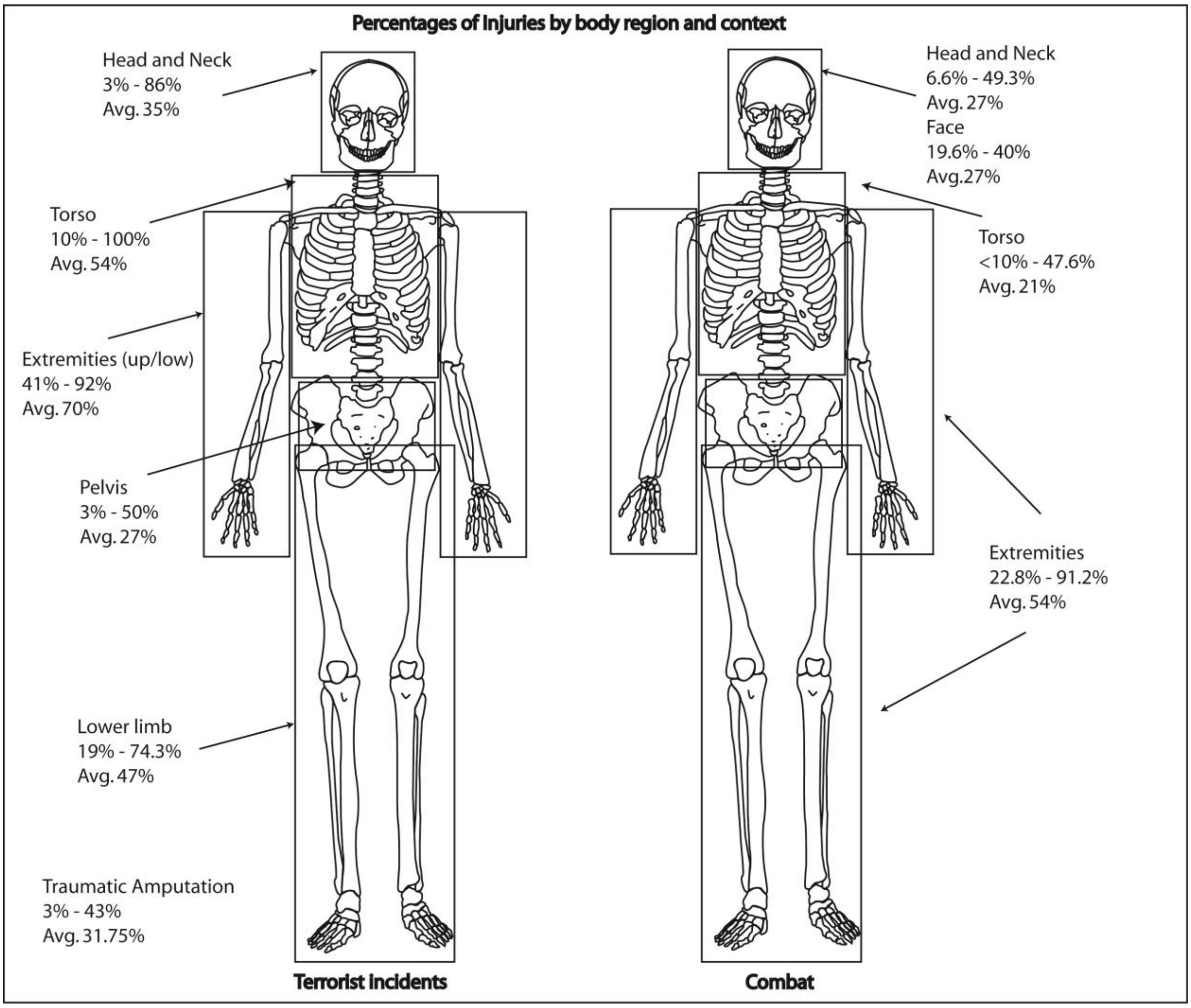

Figure 3-2: Prevalence of trauma to different body regions, comparing terrorist incidents and combat trauma (Dussault et al. In Press).

Specifically, certain types of skeletal injuries have been found in cases of terrorism. One in particular involves spine fractures, which have been found to be present in 2-5% of victims (de Ceballos et al. 2005; Gutierrez de Ceballos et al. 2005; Hare et al. 2007). This represents an injury in a very small area of the body. This is more unusual than the typical injuries in the extremities and head and neck area, which predominates most terrorism series. Vertebral fractures have also been described in combat casualties and victims. In a study of thoracolumbar fractures in combat, it was found that 38% of them were of the flexion-distraction type (Chance fracture), which in the civilian population occurs at a frequency of 1 to 2.5% of spinal fractures (Ragel et al. 2009).

Notably prevalent in terrorist incidents are open fractures (with penetration of the skin by the bone) in the long bones. In a study by Eshkol and Katz (2005), 67% of fractures were open and located in the long bones (representing 33 of 49 total fractures). Following this, the fractures were either in the facial or skull region of the body. This also represents an important pattern of injury, as an increase in the occurrence of middle or lower third facial trauma is denoted by Dobson and colleagues (1989). According to the authors, this differs from combat injuries, where increased trauma in the maxillofacial region is not observed.

Statistical studies of terrorist incident cases confirm these patterns. Hadden *et al.* (1978) examined 1532 victims of terrorist bombing and found that fractures in their cohort were multiple, compound and the lower limbs were more affected than the upper limbs. The head area was also heavily affected with 49% of males and 37% of females injured in this area (Hadden et al. 1978). Analysis of 11 terrorist bombings in Paris, occurring between 1985 and 1986, revealed the same patterns with 44.4% of injuries being in the lower limb, 23.5% affecting the upper limb and 19.3% the head and neck area. Of the injuries affecting upper and lower limbs, fracture of the lower limb was most common in the distal portion, with only one femoral fracture. The upper limb's distal portion was also most affected (Rignault and Deligny 1989). These findings also correspond to those in many other studies (Almogy et al. 2005; Sheffy et al. 2006; Torkki et al. 2006; Hare et al. 2007; Weil et al. 2007). Across the scope of these studies, a definite pattern of injury involving a high number of limb trauma and skull or facial trauma can be applied when examining an assemblage of skeletonised remains. These observations represent incidents that occurred in open contexts, which are not confined such as those happening inside a building. Due to this, patterns of injury vary to those seen in confined space terrorism.

In confined contexts, injuries to the small body areas can be quite common, as in the case with fractures of the eye socket (Thach et al. 2000). In the Oklahoma City Bombing, five percent of survivors were affected by orbital wall fractures (Thach et al. 2000; Agir et al.

2006), believed to be caused by the change in atmospheric pressure. In Mallonee and colleagues'(1996) analysis of the Oklahoma City bombing, there were 506 victims with injuries. Of these, 74% had extremity trauma and 48% had head and neck injury. These were the two most common injuries. A study by Arnold and colleagues (2004) of terrorist bombing incidents with more than 30 victims shows that there is an increase in fractures in cases involving structural collapse, with an increase in prevalence from 20% (open air) to 45%. Analysis of confined space incidents demonstrates an increase in pulmonary blast injury, pneumothorax, blast lung injury and tympanic membrane rupture due to the increase overpressure in the space (Arnold et al. 2004).These results are similar to those of studies undertaken on the trauma patterns of the victims of the Madrid train bombings (Gutierrez de Ceballos et al. 2005; Martí et al. 2006) analysis of the Madrid bombings, which also indicated that the most common area of injury involved the head and neck, followed by limb injury due to the blast and resulting fragments. Limb injury was also more predominant in the lower limb (Martí et al. 2006).

The characteristics of the blast wave in a confined environment means that it is reflected multiple times when encountering structures, which can cause a tenfold increase of the pressure, leading to a much higher incidence of primary blast injury (Brooks et al. 2011). Whilst the high number of extremity and head injuries is similar to those in open-air terrorism, a potentially higher number of blunt trauma can be observed due to the increase in tertiary blast injury and could be of use to the anthropologist. Penetrating fragment injuries can also increase due to the confined nature of the space which places the casualties and victims closer to the source of the blast.

Many studies of patterns of injury in suicide bombing have been conducted, predominantly in the Middle East (Almogy et al. 2004; Ad-El et al. 2006; Aharonson-Daniel et al. 2006; Kosashvili et al. 2009; Mekel 2009; Bala et al. 2010).These studies differ from the typical terrorist studies as these present a differing pattern of injury and involve the delivery of the explosives on a person. These studies have found that the pattern in suicide bombing fatalities is characterised by injuries to soft tissues predominantly followed by fractures, especially in the long bones (Eshkol and Katz 2005; Zafar et al. 2005; Ad-El et al. 2006). The increasing number of soft tissue injuries is due to the change in method of suicide bombing with modern explosive materials combined with metal pieces that cause extensive soft tissue penetrating injury and can cause some fracturing of bones. This represents a change in the typical suicide bombing pattern, where the severity of soft tissue damage has become more predominant than skeletal injury (Aharonson-Daniel et al. 2006) . These types of injuries are more reminiscent of ballistic trauma than straightforward blast injury. However, it still differs from gunshot wounds which can aid in the identification and differential diagnosis of these during investigation.

This is a reflection of injuries to the victims whereas suicide bombers themselves exhibit a combination of injuries which differ from the previous and are often used as the basis of identification when attempting to locate the perpetrator from the victims of the incident. Notably, severe comminution in both the soft and hard tissues in the torso area is observed rather than the less severe lacerations exhibited by those standing further from the epicentre of the blast.

Specific studies conducted on body regions affected in below vehicle terrorist bombings concur with these previous data. A study by Zafar and colleagues (2005) of a bus bombing incident in Pakistan demonstrated that the most common injuries were multiple lacerations of soft tissues and lower limb fractures. The lower limbs showed predominant injury to the distal portion of the limb, with involvement of the ankle and foot region in eleven of twelve victims (92%) due to the typical placement of explosives on the underside of vehicles. The most frequently fractured bone was the calcaneus (in ten victims). This was due to the explosive charge being placed in a car below the bus, a common method in the Middle East, and is reminiscent of patterns of injury in landmine incidents (Hull 1992; Hull et al. 1994; Hull and Cooper 1996; Zafar et al. 2005).

3.5.2. Landmine injury patterns

Landmines are explosive munitions that exhibit very distinct injury patterns. Multisystem injury is predominant in these cases, as with other situations involving explosives (Traverso et al. 1981; Meade and Mirocha 2000; Han Husum et al. 2003). Limb injury is the most predominant type of injury involving mines, with the lower limb being the most common. Three patterns of injury have been identified and described (Warden 2006).

The first pattern occurs when a mine is triggered by standing on it. This causes traumatic amputation of the lower limbs accompanied by other injuries; however, these are less severe. This can include opposite limb and scrotum injury (Nikolic et al. 2000a; Nikolic et al. 2000b). The second pattern is a random pattern of injury. Patients affected have multiple fragment wounds which may resemble the effect of grenades, which is characterised as secondary blast injury due to penetrating fragments being the major injuring mechanism. The mines capable of this damage are often those triggered by a trip wire which subsequently jump up and cause damage in various bodily areas. The third pattern is seen in those injured while handling a mine and affects predominantly the upper body, mostly the hands and face (Coupland and Korver 1991). Injuries often seen with mine incidents are soft tissue damage and fractures.

A study by Adams and Schwab (1988) of mine injuries in 15 fatalities at Guantanamo Bay demonstrated that the lower extremity injuries would have been fatal in 12 of the 15 fatalities. All 15 fatalities presented with extremity amputation, caused by either the primary blast wave or the severing of soft and hard tissue due to fragments penetrating the limb. It can be concluded that the pattern is predominantly lower limb injury (King 1969; Jacobs 1991; Meade and Mirocha 2000) and can result in as much as 90% of cases including traumatic amputation, with below the knee amputation being most common (Traverso et al. 1981). Civilian landmine injuries were analysed by Meade and Mirocha (2000) and demonstrated that over 50% of victims had injuries to the lower limb. Of these 27% were in the distal portion of the limb. This was accompanied by multiple other injuries in 60% of victims (Meade and Mirocha 2000). Additional research presented by Garner (2007), highlights that stress fractures are caused by the shock wave from the landmine and the associated energised gases and products result in detachment of limb, related to torsion, bending and dynamic overpressure. The hypothesis presented is that traumatic amputation is caused by these actions. Based on previous research undertaken by Hull and colleagues (1992; 1994; 1996), it is entirely plausible that these conclusions are correct as the mechanism is the same as that found in traumatic amputation related to other types of explosives. Here, the sole difference would be in the direction of the blast, with the physics of the blast remaining the same. In suspected landmine injury, this type of pattern can be useful in correlating injury to incident context. . For this information to be useful in the context of anthropological investigation, further study and expansion of samples would be necessary, such as experimental work done with cadaveric or proxy bone. Examination of the fracture types from different landmine types would elicit more distinguishing features which can be used to explain context, rather than a focus on the soft tissue injuries which the clinical and medical management literature centres upon.

A notable characteristic of landmine injury is the common presence of calcaneal fractures. Studies have indicated that this is repeatedly the most common fracture encountered in landmine injury (King 1969; Jacobs 1991; Nikolic et al. 2000b). This reveals a characteristic injury that is useful in the identification of landmine blast injury. This is also a common injury in under-vehicle blasts, necessitating the contextualizing of incidents and the holistic examination of the pattern of injury to aid in the differentiation of the two types of injuries.

3.5.3. Combat injury patterns

Patterns of injury in combat remains a central concern in this thesis to achieve the objective of differentiation of combat injury and human rights violations based solely on the skeletal evidence. To accomplish the recognition of differences between the two contexts, a review of previously examined research identifying trends in injuries due to combat blast is presented below.

The current body of knowledge regarding blast injury focuses predominantly on the medical management of these injuries and the majority are found in the medical literature. These studies are often retrospective and focus on pairwise comparison of groups and the body regions affected to identify any significant prevalence of injuries. This is an epidemiology and management approach which can still provide information for the post-mortem identification of blast injury in the skeleton but requires the examination of data primarily aimed at clinicians to ascertain what can be of use to the anthropologist.

Despite this, the information provided from these studies can indeed provide materials that can be used in the differentiation of combat trauma due to blast from the patterns seen in civilian blast trauma. Predominantly, the type of injury seen in combat is related to secondary trauma, inflicted by fragments (extraneous to the explosive itself or from the surrounding environment). A study by Lin *et al.* (2004) highlights that in a sample of soldiers injured during Operation Enduring Freedom (Afghanistan 2001- present), 65% of injuries can be attributed to fragments. This is a reflection of the nature of blast materials used in combat situations, which has seen an increase in the use of improvised explosive devices (IEDs) whose purpose is to maximise wounding potential through incorporation of additional materials to create an increase in the number of fragments. The increase in secondary blast trauma type injuries is also related to the use of protective clothing and armour by troops, thus reducing the amount of exposed soft tissue and mitigating some of the injury potential (Belmont et al.; Blumenfeld 2005; Wolff et al. 2005; Belmont 2010). Additionally, the removal of troops from the immediate vicinity of blast, through armoured vehicle use, results in less severe injury patterns than those seen in civilian situations. The prevalence of trauma in combat contexts is illustrated in Figure 3-2.

Also of interest is the removal of troops from close-range combat, resulting in the increased use of materials such as improvised explosive devices and anti-vehicle mines rather than guns. Consequently, a rise in the number of casualties affected by blast injury is seen over the course of modern warfare and with it an accompanying change in patterns and severity of injury (Owens et al. 2008; Lew et al. 2010; Navarro Suay et al. 2012; Wallace 2012; Zachar et al. 2013). A study by Navarro Suay *et al.* (2012) examined casualties from Afghanistan, comparing the damaging agent (explosives versus gunshot wound) and classified these by body region affected. The authors found that in all regions except the head, explosives were the injuring mechanisms. The most affected area was the limbs, resulting from their exposure (rather than the protected torso) and their high surface area. As with civilian trauma, the lower limbs were greatly affected by trauma; however the head was not. This is likely due to the use of head protection by soldiers, which has been standard for many years. As indicated by other studies (Peleg et al. 2004), the severity of gunshot wounds was higher than blast injury and resulted in much more extensive skeletal injury (a higher level of comminution). Conversely, Gofrit *et al.* (1996) studied patterns of injury from Lebanon on the patterns of injuries from firearms and shrapnel analysed the incidence of injury with the purpose of evaluating the suitability of body armour used during this conflict. The authors concluded that the anatomical location of fatal injuries from shrapnel followed a definable pattern. This included a large proportion of injuries to the front and middle of the torso, found in 64% of their cases. The head was also an area of significant injury, particularly the front area (70%). The facial area was also heavily affected with a high density of trauma. With the recent Afghanistan war being one fought with the extensive use of body armour by troops, the difference between the two patterns of injury can clearly be attributed to this.

As with civilian terrorism blast incidents, the context also affects the outcome. Open-air and enclosed environments create different patterns of injury, with enclosed vehicles being the source of much research for the characterisation of injuries in combat. Notably, the Ramasamy *et al.* (2011) study presents data comparing open versus closed environments in combat and shows a predominance of lower limb injuries, in the tibia, fibula and foot, to be affected in enclosed situations. Additionally, a significantly higher number of tertiary injuries also occur in these situations.

Rather than examining specific situations to analyse, other studies have examined conflicts (Iraq and Afghanistan) or particular groups within battalions. Comparison with previous conflict patterns of injury is also presented to contrast those from modern combat (Gondusky and Reiter 2005). This has yielded a large number of retrospective studies providing valuable information to the anthropologist. The following section synthesises patterns of injuries from these studies.

Historically, examination of the patterns of injury in previous conflict has yielded information which demonstrates a change in the body regions injured. From World War II onwards, the extremities and head/neck region were affected greatly. Over the course of the following conflicts (Korean War, Vietnam War, Gulf War, Somalia) the amount of head and neck injuries decreases, but the prevalence of extremity injuries remains relatively stable and subsequently increases drastically during the first Gulf War and Somalia. The link with body armour including head protection is obvious, making this information useful to anthropologists working in combat casualty recovery (such as those working with the U.S. Government in the Middle East). A decrease in eye injury is also noted (Gondusky and Reiter 2005), related to the use of eye wear protecting from fragments. Particularly of note is the inclusion of data from the Bosnian and Croatian war, of which includes a prevalence of 9.8% of eye injury (this could include soft tissue and musculoskeletal).

Examining a specific conflict (Operation Iraqi Freedom and Operation Enduring Freedom), Owens and colleagues (2008) (Owens et al. 2008)compared body regions affected by three different mechanisms; gunshot wounds, explosion and motor vehicle collision. Most notable is the very high predominance of head and neck injury in those affected by explosion. Comparatively, the gunshot wound casualties had thorax injuries as their highest area of trauma and the head and neck as the lowest. The number of extremity injuries was also much higher than both the gunshot and collision victims. In the examination of a mechanised battalion in Iraq, head and upper extremity injury is described as being most prominent, a factor resulting from the lower body protection offered by the vehicles in which these soldiers were seated (Gondusky and Reiter 2005). In this study, 97% of the sample's injuries were the result of explosions or IED's, a negligible amount from gunshot and other sources. Particularly important is the low number of chest and back injury, again reflecting the protective aspect of body armour employed by modern soldiers.

Common in the clinical literature are studies which are aimed at the medical management of combat injuries, requiring a more critical analysis to be able to evaluate how useful to anthropology the information presented can be. Whilst a large number of these papers may not be of use, parts of others can still be useful such as those which are more particularly aimed at orthopaedic practitioners. Additional knowledge of orthopaedic terminology is required and understanding of the different notation systems used to describe fractures important. One such classification is used in a study by Gwinn *et al.* (2011), the orthopaedic trauma association classification which uses a number representing the bone, followed by a combination of a letter and up to three numbers representing the types of fractures as well a level of comminution (Marsh 2009). Familiarity with this system permits the anthropologist to analyse orthopaedic literature which can be useful to research. Particularly, the Gwinn *et al.* (2011) study examines the patterns of lower limb fractures from a sample of soldiers with fractures accompanied by arterial involvement. The results of this study are confined to below the knee injuries and highlight an abundance of metatarsal fractures, comminuted posterior facet and body fractures in the calcaneus and neck fractures in the talus. The tibia and fibula were most affected by fragmented wedge fractures and complex (comminuted) irregular spiral fractures of the diaphysis. Whilst caution should be noted in the interpretation of these results as they represent a sample which is selective of those with arterial injuries in the U.S Marine Corps, the trends in the patterns of injury in the lower limb of dismounted soldiers can be of use. In this study, evidence of comminution is seen in the most common injuries, giving an indication of mechanism that can be correlated to secondary type trauma, which typically results in a higher level of comminution.

A second study on dismounted combat troops was undertaken by Jacobs (1991) specifically examining the incidence of traumatic amputations and their orthopaedic characteristics. Traumatic amputation, being a particular injury, is very important to both medical staff and can be an indicator of certain types of blast injury for the anthropologist to identify. The authors classify types of traumatic amputation by level of injury and their results demonstrate that the largest proportion of traumatic amputations occur in the proximal lower leg or the distal thigh. In cases where both legs are amputated by the blast mechanism, 48% of the sample exhibited amputation at the same level as those only having a single amputation. An important difference between these two patterns is the presence of pelvic fractures solely in the group with bilateral amputations. Notably, the authors address limitations extensively and state that the examination of the sample was preliminary and further study needs to be undertaken. However, important results that can help to classify combat patterns of injury are discovered, particularly the association of pelvic ring fractures with bilateral traumatic amputation.

In civilian trauma patterns an important contextual consideration is the difference between open air incidents and confined space incidents, which involve different mechanisms of injury. These also apply to trauma patterns in a combat situation as well, such as that which occurred on the USS Cole Navy destroyer bombed in 2000. In a study of the orthopaedic injuries of survivors of the bombing (Lambert et al. 2003) the proportion of victims with lower limb injury is 61%, similar to that of studies examining other confined space incidents, as previously examined. In the sample, orthopaedic injuries are present in 40% of the survivors, following the notion that orthopaedic injuries are highly prevalent in combat situations. In the lower limb fractures from this study, most are open fractures indicating a severity of injury. The upper limb injuries are a few isolated fractures in the shoulder complex and wrist. Most cases involve unilateral injuries, potentially indicating directionality of the victim in relation to the blast. None of the cases studied had orthopaedic head injuries.

Table 3-1: Summary of data from studies on combat related trauma

Study	Context	Blast injuries	Additional Conclusions
Lin *et al.* (2004)	Afghanistan	65% fragmentation injuries	
Navarro Suay *et al.* (2012)	Afghanistan	Trauma to all regions except head, limbs most affected	
Gofrit *et al.* (1996)	Lebanon	64% front/middle of torso. Front of head 70%	
Ramasamy *et al.* (2011)	Enclosed combat (ie. Tank, armoured vehicle)	Predominantly lower limb.	Tibia, fibula, foot affected. High # of tertiary trauma
Owens *et al.* (2008)	Iraq and Afghanistan	High predominance of head/neck injury in explosives casualties. High # of extremity injuries.	Thorax injuries most common in gunshot
Gondusky and Reiter (2005)	Mechanised battalion, Iraq	Head and upper extremity injury	Vehicle provides protection to rest of body
Jacobs (1991)	Dismounted combat troops	Traumatic amputations (predominantly proximal lower leg/distal thigh)	Pelvic ring fractures noted in bilateral traumatic amputations
Lambert *et al.* (2003)	Confined space (USS Cole)	61% lower limb injury, 40% survivors with orthopaedic injuries	Open fractures predominant in lower limb

Whilst these studies indicate a general pattern on can expect in a variety of combat related blast situations, there are a few types of injuries which stand out due to their prevalence being notably higher in the combat population rather than civilians. In the examination of combat related spine injuries, an increase in certain types of fractures is seen such as Chance fractures and lower lumbar burst fractures, which have a very low incidence in the general population (Covey et al. 2000; Kang et al. 2011) and in combat are related to anti-personnel and anti-vehicle mines. Maxillofacial injuries are also predominant in combat situations, with injuries involving the maxillofacial sinus areas and the mandible (see section 3.6).

As shown through various studies, the pattern of injury in combat favours extremity trauma (Lakstein and Blumenfeld 2005) and can be attributed to the use of body armour in modern combat. Particular types of fractures and patterns are linked to modern combat aspects, such as those seen in the spine and their relation to the nature of combat in vehicles. Combat blast injuries can be characterised as being caused predominantly by fragmentation mechanisms and attributed to secondary blast injury. A decrease in head trauma between historical wars and modern warfare is also characteristic to combat. Eye injury, present in civilian trauma (Thach et al. 2000; Mehta et al. 2007), occurs much less frequently in modern combat. This is again related to the level of protection employed by modern battalions.

3.6. Potential skeletal indicators of blast injury

Of the four categories of blast injury, primary blast injury research has focused on the organs of the torso, such as the lungs and bowels (Mayorga 1997; Ritenour and Baskin 2008; Wolf et al. 2009), not the musculoskeletal system. However, current research demonstrates the prevalence of musculoskeletal injuries caused by the primary blast wave (Hayda et al. 2004). This has implications for anthropological investigation of blast injury, providing indicators of primary blast injury that can guide anthropological investigation.

3.6.1. Maxillofacial trauma

One example of recently studied skeletal blast trauma is the injuries occurring to the maxillofacial region of the skull. Two biodynamic processes act on the maxillofacial area of the human skeleton; implosion and explosion (Shuker 1995; Shuker 2010). As the shock wave passes through the air filled cavities in the sinuses of the maxillofacial area, the air implodes under the high pressure effects, causing damage to the skeletal structures. The rapid external loading of the pressure onto the sinus structures, compresses the sinus walls and cause them to splinter (Shuker 2008b; Shuker 2010). Once the high pressure has abated, the air re-expands, effectively causing a miniature explosion within the structures. This causes more damage to the delicate structures of the nasal area. This type of injury occurs when the shock wave hits the mid-face area, perpendicularly and straight on. When a lateral wave is coupled into the skeletal structures of the skull, the lateral portion of the maxillary sinuses are less affected due to the thicker zygomatic buttresses deflecting the shock wave more effectively than when the force is applied perpendicularly to the front of the face (Shuker 2010). In a study of 17 patients from the Madrid train bombings, Marti *et al.* (2006) identified paranasal sinus fractures in 53% of those with severe injuries, corresponding to primary blast injury patterns.

A new type of primary blast injury has been described by Shuker (2008a) following extensive blast trauma examination in Middle East conflicts. This injury represents the effect of a shock wave travelling transversely through the mandible, causing a shearing fragmentation at a point of weakness, the mylohyoid line(Shuker 2008a), illustrated in Figure 3.3. At the mylohyoid attachment, the two types of bone (cancellous and cortical bone) split transversely due to the differing densities absorbing the shock wave differently (Shuker 1995; Shuker 2006, 2008a).

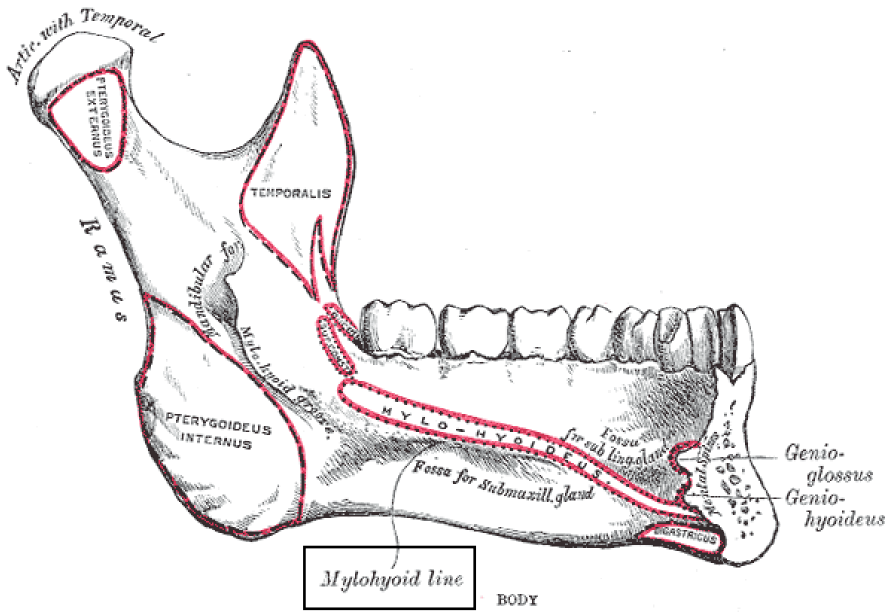

Figure 3-3: Diagram of interior aspect of mandible, illustrating the mylohyoid line (Lewis 1918)

These effects present as a transverse fracture line that is located below the apex of the roots of teeth, often occurring at the level of the third molar apex and parallel to the angle of the mandible. This can be seen as more than one fracture line when one part of the mandibular bone shears over the other to create parallel transverse horizontal fractures (Shuker 1995; Shuker 2006).

This pattern of injury differs from mandibular fractures caused by trauma unrelated to blasts. Typically, the fractures in the mandible seen in these cases are vertical due to one specific trauma impact point rather than a shock wave passing through the mandible (Shuker 2008a). Various studies of facial fractures have examined the incidence and aetiology of mandibular fractures, along with experimentation to determine the points of weakness and stress in the mandible (Allan and Daly 1990; Luyk and Ferguson 1991; Nomura et al. 2003; King et al. 2004; Torreira and Fernandez 2004).

These findings outline the typical biological response to high impact forces at the various points in mandible and the potential for fractures. Based on forces exerted it would be possible to assume that shock waves can indeed produces fractures when impacting the mandible in the symphysis area. However, the patterns of injury differ from the traditional mandibular trauma in that the expected symphyseal, condylar and angle fractures are exhibited very differently from the transverse fractures in the body of the mandible (Luyk and Ferguson 1991; Torreira and Fernandez 2004). An examined transverse fracture pattern in the mandible may be useful in the identification of potential blast injury in the human skeleton. A recently published article by Breeze *et al.* (2010) examined this type of injury and studied its incidence in a sample of British soldiers. Their results indicated that this was actually not common in battle wounded soldiers and questioned the validity of Shuker's methods and sample. This should be taken into account when furthering the research on indicators of blast injury. Despite disputing Shuker's findings, Breeze *et al.*'s conclusions contribute some interesting possibilities for primary indicators. Their research indicates an increased number of pterygoid plate fractures in fatalities (Breeze *et al.* 2010). This study also demonstrates that the distribution of mandibular fractures in the sample resembles the distribution of fractures in blunt trauma to the mandible. This could indicate that the blast wave mimics blunt force when imparting simple fractures. Comminuted fractures are consequently more likely to represent secondary blast injury from fragments to the mandible, causing penetrating injury. Whilst these conclusions are informative and helpful, the sample population is one taken strictly from combat related incidents, making the conclusions potentially inapplicable to civilian trauma from blast.

Additionally, in the mandibular area, a pattern of injury in the teeth has been described. Following blast injury studies, Shuker (1995; 2008a) identified tooth transections located below the gingival margin at the cemento-enamel junction. This location is a point of weakness for the teeth. The areas of protection provided by the root and alveoli cause some of the transverse force to be reflected. The remaining force causes transverse tooth shear which is parallel to the transverse mandible fractures, at the cemento-enamel junction of the teeth resulting in loss of the upper portion of the teeth (Shuker 2008; Shuker 1995).

3.6.2. **Traumatic amputation**

Primary blast injury is not confined to cranial trauma and can be observed in the extremities in the form of traumatic amputations. It has been a long standing conclusion that traumatic amputation is actually caused by the blast wind element of an explosion, in a pattern mimicking that of pilot ejection injury patterns (Horrocks 2001; Hull 1992; Hull and Cooper 1996). It was believed that limb flailing, where it is displaced wildly due to the blast wind, occurs before the traumatic amputation, causing the extremity joints to be the common site of amputation. This type of injury is seen in ejecting pilots, with the jet wind causing similar dynamic forces causing flailing of the loose limbs. However, this is a differing mechanism of injury to what is seen in previous traumatic amputation research (Hull 1992). In the numerous Hull and colleagues studies, the sample is taken from a variety of sources and combines methods to examine the phenomena of traumatic amputation using case studies, mathematical modelling and experiments, making the argument more persuasive that the mechanism of injury is in fact different to the previous thesis (Hull 1992; Hull et al. 1994; Hull and Cooper 1996).

The previously held notion was that flailing of the limb occurred relative to the torso, causing a fracture or dislocation followed by avulsion at the joint of the extremity. This causes failure of the limb at the limit of movement in the joint (Hull 1992). However, studies conducted by Hull *et al.* (1994), Hull (1992) and Hull and Cooper (1996) contradict this notion. These studies demonstrate that the most common site of amputation was not at the joint but at different positions along the long bones, according to the context of the explosive event. The sites of amputation observed were most frequently the lower third of the femur and the upper third of the tibia (Hull and Cooper 1996) at the level of the tibial tuberosity (Hull 1992). In the upper limb, the distal portion was predominantly amputated (Hull 1992). Traumatic amputations were also linked with a high incidence of mortality, a view commonly reflected in the literature (Hull 1992; Leibovici et al. 1996; Chaloner 2005; Garner 2007). The authors found a high number of transverse and oblique fractures of the long bones at the site of traumatic amputation (Hull et al. 1994). This could be interpreted as a reflection of the characteristics of the shock wave, which travels from the epicentre of the blast, expanding outwards. This may potentially help to indicate directionality of the blast or indicate the positioning of victims relative to the blast and requires further investigation.

What causes traumatic amputations, if the commonly held hypothesis of avulsion at the joint due to blast wind, is not valid? Through finite element modelling, Hull and Cooper (Hull and Cooper 1996) were able to test the hypothesis that a coupling of shock waves causes the traumatic amputation through the long bones rather than flailing followed by avulsion through the joint. The mathematical modelling of the lower limb resulted in evidence that the shock wave causes a stretching and bending in the mid-diaphysis region of a long bone (Hull and Cooper 1996)(Hull and Cooper 1996). Measurements showed that a minimal pressure of 133 megapascal (MPa) causes stress waves within the bone, which is sufficient to cause fracturing of the bone. This occurs less than 200 milliseconds after an explosion. Further whole body modelling demonstrated that flailing of the limbs occurs after 200 ms, which is subsequent to the shock wave stressing the mid-shaft area of a long bone. With this modelling, Hull and Cooper (1996)demonstrated that the fracturing of a long bone, due to stretching and bending at the mid-diaphysis, occurs before the flailing.

To verify the mathematical models created, blast trials were conducted using goat bones (Hull and Cooper 1996). Previously observed patterns were replicated. Femora fractured in the upper and mid third and tibia sustained damage at the mid-diaphyseal level, showing simple oblique fractures. The knees also lacked any ligament damage or disruption, demonstrating that the shock wave was not acting on the joint to cause amputations. These observations are consistent with the modelling of the femoral and tibial fractures. Hull and Cooper (1996) concluded that the comminuted femoral fractures were likely due to high axial forces combined with extension of the bone, whilst the tibial fractures were likely to be subjected to less force. The observed simple fractures demonstrate a lower force acting on the tibial bone. Blast trials using legs wearing boots were subjected to land mines were also conducted by Wolff and colleagues (2005). They concluded that at 0.02 seconds following the blast, movement of the leg occurs and is then followed by the amputation. None of their trials concluded that damage occurred at the joint.

These replicable studies demonstrate a mechanism that involves damage to the skeletal system useful in the investigation of post-mortem trauma from suspected blast injury. These show promise as a way of identifying this type of trauma by the biological anthropologist. Further studies are required to continue this work and assess the application of these in anthropological contexts, an activity currently out of the scope of the present research.

3.6.3. Inner-ear involvement

Hollinger *et al.* (2009) investigated the incidence of luxation of the ossicular chain and fracturing of the petrous bone. This was done using multislice CT scanning on corpses. Part of this research included the incidence of these injuries in gunshot trauma. Despite the difference in characteristics of firearms trauma, much of the action of projectiles from explosions follows some of the same ballistic properties and this study's conclusions could possibly indicate another avenue of research in the identification of skeletal trauma from blast. Hollinger *et al.* (2009) found mid-ear lesions, including petrous pyramid fractures and ossicular chain disruptions, occurred frequently in mechanical trauma and extreme heat cases, both of which can be characteristic of explosions. Gunshot wounds were found to have a high incidence of transverse petrous fractures. Longitudinal or combined fractures were also noted, but did not have the same frequent incidence. They posited that these fractures were the result of direct deformation and the hydrodynamic effect of the projectile in the cranium. Both of these effects can be logical expected in the cranium in case of explosions as well, likely due to the shock wave and the effect of any penetrating projectiles. A high number of ossicular chain luxation was also noted in the gunshot trauma group and it was speculated that the projectile can give rise to high amplitude and short time vibrations of enough energy to cause the disruption of the ossicular chain within the petrous bone. Vibrations of this nature can also be found in explosions and could theoretically cause the same type of injuries in the cranium. The shock wave component of the blast could exert a similar mechanism on the middle-ear structures and cause similar injuries, necessitating further research. Marti *et al.*'s study (2006)of the Madrid bombing indicates that petrous fractures are found in blast injury cases. They observed that 18% of their patients had petrous fractures.

3.7. Comparison with ballistic injury

Basic understanding of ballistic mechanisms in bone is necessary to compare the trauma encountered in blast injury to that seen in gunshot wound cases. The following section outlines ballistic mechanisms and the resulting injuries in the skeleton that permit the identification of gunshot wounds in bone.

3.7.1. Gunshot wounds

Anthropologists can begin to identify blast injury in assemblages by observing the overall patterns of a sample and specific skeletal injuries. The pattern of injury includes a high number of extremity trauma, particularly in the lower limb. The level of comminution (producing multiple small bone fragments) in fractures also differs from gunshot wounds. Firearms cause skeletal injuries which have been well-documented. Low-velocity projectiles from firearms cause drilled whole defects in cancellous bone such as in the pelvis, distal femur, proximal humerus and spine. When a ballistic projectile impacts solely through cortical bone, tangential bone defects are often observed (butterfly fracture type). Spiral and transverse fractures characterize the path of low-velocity projectiles impacting dense diaphyseal cortical bone (as in the femur) (Gugala and Lindsey 2003). High-velocity gunshot wounds, particularly in long bones, exhibit extensive comminution (Vogel and Dootz 2007), whereas shrapnel injuries induced by projectiles from an explosion cause significantly less damage. This is due to the irregular shape of shrapnel, which causes it to travel at a lower velocity than ballistic projectiles. The velocity of shrapnel drops off extensively the further a person is from the epicentre of the blast (Cooper et al. 1983; Wiener and Barrett 1986; Boffard and MacFarlane 1993; Covey and Born 2010) .

Studies comparing the patterns between firearms injuries in terrorism and minor warfare and blast injuries have been conducted by researchers in the Middle East (Peleg et al. 2004; Sheffy et al. 2006). These have yielded conclusions which can also aid in the differentiation of firearms and blast injuries in assemblages. Commonly found in gunshot wounded victims are injuries to the chest, spine and abdomen (including soft tissue injury) and are found to typically affect only one or two body regions. Conversely, Peleg *et al.* (2004)found that blast injury affects the pelvis, extremities and large numbers of head and brain injuries. The number of fractures was also higher in gunshot wounds. Sheffy *et al.* (2006)compared gunshot wounds to secondary fragment injuries in blasts. Their findings are similar to those of Peleg *et al.* (2004), which noted secondary fragment trauma to be prevalent in the upper body region, particularly the head and neck. The damage was less extensive than localized gunshot wounds as these were produced by small sized fragments with much lower velocity and impacted upon areas which are less protected by clothing or other external coverings (Sheffy et al. 2006).

3.8. Limitations of the current state of knowledge

This literature review demonstrates that the main body of research is focused on the medical fields, such as triage, management and surgical intervention. These areas of research are well-developed and are the main concern of most researchers in these studies. This has been the focus since before the Great War, with the care of the large number of wounded from battle precipitating the need for development of medical expertise on these types of injuries (Fulton 1942; Mellor 1988; Beekley and Watts 2004; Geiger et al. 2008; Belmont 2010; Lew et al. 2010). Throughout the years, the techniques developed in military medicine trickled down through personnel acquiring knowledge from the military on dealing with blast trauma in civilians. This, along with a focus on the military traumatic brain injury, is the current focus of research (Okie 2005; Finkel 2006; Warden 2006; Bochicchio et al. 2008; Buchanan 2008; Elder and Cristian 2009; Wallace 2009).

Forensic and biological anthropology does not have a significant body of literature on blast injury despite the use of their professionals in situations calling for analysis of this trauma. A few select case studies and a chapter on the basics of blast injury can be located (Pathak et al.; Siciliano et al. 2000; Allaire and Manhein 2008; Kimmerle and Baraybar 2008;

Dussault et al. In Press). The forensic sciences concentrate on the chemical identification of explosive materials, the use of DNA extraction from remains injured in blasts and pathology cases regarding soft tissue injuries (Rajs et al. 1987; Beveridge 1998; Botti et al. 2003; Kuila et al. 2006). Whilst this provides an important body of knowledge forensic anthropology could benefit from consistent descriptions of blast trauma to apply when analysing injuries to the skeleton. Consistently, forensic and biological anthropologists are called in to participate in cases involving blast trauma, such as the identification of remains by the Commonwealth War Graves Commission and the Joint Prisoners of War, Missing in Action Central Commend- Central Identification Laboratory of soldiers from previous conflicts where use of explosive materials is known.

Another important example of the anthropologist as practitioners is in the analysis and identification of remains from Bosnia in the late 1990's. The cases from Bosnia which have been presented to the International Criminal Tribunal for the Former Yugoslavia, at The Hague, have actually brought into question whether trauma inflicted in a case involving blast was perpetrated during warfare or was in fact a human rights violation against civilians. Defence attorneys in the ICTY cases against Tolimir, Karadžić and Mladić (ICTY. 2010a, ICTY 2010b, ICTY2012a, ICTY 2012b) stipulated that the injuries seen could have been from battle rather than rights violations. Differentiating the patterns of injury between combat injuries and civilian injuries would be beneficial to indicate if there is a distinction between the two, which would be useful in answering these types of questions.

There has also been a shift in the medical literature towards the investigation of primary blast injury, including maxillofacial trauma and traumatic amputation in the skeleton. These developments pose an interesting question as to their applicability as an indicator of blast injury in the skeleton, something that has not been previously investigated, and can serve to demonstrate primary blast effects, previously believed to not affect bones. Further investigation is warranted to determine the investigational applications of this and how these can contribute to furthering the field of anthropology. These types of investigations are also highlighted by recent developments in the analysis of trauma patterns from a forensic point of view (Ramasamy et al. 2010), illustrating the multi-disciplinary approach which can be beneficial in this field of research.

The literature review on blast trauma demonstrates that there are limitations in the existing research when needing to apply this to anthropological case work. The focus on medical aspects of blast trauma ignores musculoskeletal information which could be of great use in the investigation of blast events from the past and present. The paucity of anthropological information regarding these injuries is evident and could benefit positively from clarification and expansion of the little existing material to better serve trauma analysis in situations encountered by the practitioner such as historical casework, human rights violations, and terrorism and individual case studies of skeletonised remains.

3.9. Trauma studies and statistical methods in anthropology

To select appropriate methods for this study, a necessary examination of trauma studies in anthropology is undertaken to determine the current methodologies employed by anthropologists. In anthropology, the current state of knowledge regarding blast injury is very small and is comprised of case studies (Al Mulla et al. 2001; Alempijević D 2008; Allaire and Manhein 2008), an introduction to blast injury and related case studies (Kimmerle and Baraybar 2008) and a pilot study involving blast trials (Christensen et al. 2012) examining the nature of primary and secondary blast injury in porcine proxies.

Due to the nature of the few articles in the anthropological literature, an examination of anthropological studies of large assemblages and the techniques for the analysis of trauma within these was undertaken. Particular attention is paid to the method of the analysis, specifically those which involve statistical methods, as these can provide quantifiable results which can serve the purposes of court bodies, such as the ICTY. With this, potential gaps in the methodology can be identified and a new set of tools proposed. This new set of tools will then be examined in the anthropological context to identify current work which applies these and how these could be used in trauma studies.

In the review of anthropological studies, statistical tests commonly employed were those using pair-wise comparisons. The most encountered test was the χ^2 test, used to compare prevalence of certain types of trauma within groups, between groups, temporally and between locations. Similar to this are the Fisher's Exact test and Pearson' r, which are also used in a pairwise methodology to compare two groups, sub-groups or variables.

Trauma studies from the 1990's and the 2000's focus on prevalence of injuries and characterising the frequency of these in comparison to another sample. Even when addressing "patterns" of injury, it is mostly a description of the samples and the prevalence of different types of injuries or characteristics of one type. Basic statistics are employed, not venturing much further than essentially descriptive statistics, counts and prevalence percentages. Using these methods in the analysis of trauma, various authors achieve information on between group comparisons, such as those between sex groups (Erdal 2012) alongside comparisons of different types of trauma (Scott and Buckley 2010). The most predominant approach is a calculation of frequencies, or counts, of injuries (usually fractures) (Judd 2002). This is used for comparison by employing the Pearson's χ^2 statistic (and its associated tests such as Fisher's and Pearson's r) such as the work seen in the analysis of cranial trauma presence (Owens 2007).

3.9.1. Cluster analysis and pattern detection in anthropology

Current statistical analyses being undertaken to examine injuries in the human skeleton in paleopathology and bioanthropology utilise frequencies, prevalence percentages and simple Chi-Squared or Fisher's exact test to identify significant differences between frequencies of observed injuries or groups of injuries. Whilst these tests will elucidate important information regarding the statistical significance of differences between observed frequencies, it cannot help to classify objects into groups, whether these be individual injuries or complexes of injuries.

The purpose of this research is to identify patterns within the data which help to differentiate between blast injury and other types of trauma, specifically gunshot wounds. Also, the differentiation between combat contexts and others is an objective which will be achieved by employing statistical methods to achieve robust quantifications of the probability that the trauma identified is indeed blast injury and can be attributed to a certain context.

Pattern detection methods such as cluster analysis are not commonly used in trauma analysis but can be found in archaeology, such as ceramic classification (Karasik and

Smilansky 2011), and in some anthropological sub disciplines, such as biogeography (Yongyi et al. 1991). One example is the use of hierarchical cluster analysis in to examine patterns of resource utilisation by analysing coprolites and identifying patterns of food combinations giving an insight into diet (Sutton and Reinhard 1995). In archaeology, this statistical approach has been employed in the analysis of architectural features. In the research by Pugh (2003), cluster analysis is employed as an exploratory method to identify patterns which can be used as types in further spatial analysis. This type of application of cluster analysis as an exploration of patterns would be ideal in the examination of the samples in this piece of research due to the fact that it has not been previously approached. Karasik and Smilansky (2011) also point out that this type of pattern detection is "a convenient research tool which provides a systematic basis for further analysis".

Combining cluster analysis with other statistical testing to explore the groups formed is the subsequent step taken by many researchers. This involves the often involves techniques to identify important variables that can indicate groupings and employ multivariate techniques which would be suitable to this piece of research.

3.9.2. Multivariate methods in anthropology

Multivariate methods are complex and there are many which have been applied in archaeology and anthropology. One of the predominant uses of multivariate analysis is in the examination of ancient DNA. Principal components analysis is often used with aDNA analysis. This is used to examine similarities or differences between populations on two-dimensional plots, with the dimensions reduced to the variables which contribute most variance (Kaestle and Horsburgh 2002). Variations on these types of techniques are employed as well, based on the nature of the data, such as multidimensional scaling and correspondence analysis.

Population structure studies also employ various multivariate methods, both with models and without. Relethford and Lees examined the statistical methods in population studies and highlighted the use of many different techniques to highlight the degree of and factors affecting variation between groups such as discriminant analysis (Relethford and Lees 1982). This type of analysis could be useful when comparing two groups of trauma patterns to determine where these differences/similarities lie and which variables contribute to this.

These methods are also employed when examining physical traits in populations, such as craniometrics (Key and Jantz 1981) and morphological characteristics (Masters and Lubinsky 1988; Bruner et al. 2013; Kurki 2013)

3.9.3. Logistic regression

Logistic regression, in the form of binary logistic regression or a mix of continuous and categorical variables has been employed in anthropology for many research purposes. Typically used to predict association with a specified group or examining odds ratios, different anthropological sub disciplines have employed this statistical technique. For example, longevity and its relationship with stature was examined, predicting that the odds of survival beyond 40 years of age increase with stature (Kemkes-Grottenthaler 2005).

Differentiation between the biological sexes using logistic regression has also been undertaken, using morphology and metrics (Konigsberg and Hens 1998; Júnior et al. 2007) to determine predictors of sex based on cranial characteristics. Non-metric traits, such as Carabelli's cusps, have also been examined for indicators of relationship. Presence and size of the hypocone along with accessory cusps were found to covary with Carabelli's cusp and increase the likelihood of its presence (Moormann et al. 2013).

The use of logistic regression in the prediction of the source of violent trauma has not been undertaken. Subsistence and physical activity prediction has been undertaken. Campanacho and colleagues showed no greater degeneration in the pubic symphysis in skeletons with an indication of greater physical activity in life (2012). (Baker and Pearson 2006) Baker and Pearson found sex differences in the risk of shoulder osteoarthritis in prehistoric populations.

3.9.4. Application to trauma analysis

These statistical methods have not been previously applied to the analysis of trauma in anthropology. It is demonstrated here that this methodology can be useful in the identification of patterns in the samples and analysis of relationships and prediction potential for body region patterns in the studied groups. The suitability of these methods is examined in greater detail in chapter 5.

3.10. Summary

The practice of examining studies for injuries from blast injury requires the researcher to address the generalisations in the resulting information. Predominantly, the data that can be collected from the clinical literature typically do not separate soft from hard tissue injury, unless otherwise specifically indicated. However, value still resides in this information, permitting a holistic approach to establishing potential patterns of injury. It is apparent that areas affected by blast injury in the soft tissues could also be affected at the skeletal level, depending on the context of the situation. Using this information can be beneficial and indicate which areas of the body are susceptible to injury which could potentially include skeletal trauma.

The literature has shown distinct patterns of injury in bomb blast situations, both civilian and combat related. Techniques which will be explored for the identification and prediction of blast trauma using statistical analysis were found in many disciplines found in clinical medicine, anthropology and archaeology. Expansion on this will continue in the methods chapter and be explored in the context of samples collected from sources presented in the following chapter, Materials.

4. Materials

4.1. Introduction

This chapter outlines the materials that were used in the research project which includes data from mass graves in Bosnia and cases of killed in action Canadian soldiers from World War One. The materials are described, their historical background and acquisition explained. This includes highlighting the relevant permissions for the research and the scope with which these materials can be used for the purposes of the research. Issues regarding confidentiality are addressed for the Bosnia sample, explaining the implications of using the materials provided by the International Commission on Missing Persons and the guidelines imposed for the use of the data provided.

The nature of the data is explained, including how the data is presented in the raw materials and how it is presented for the purposes of this research. This will lead into the methodology, which explains why the data was used and how it was used in the specific format that was adapted for the analysis.

4.2. Bosnia

The majority of the anthropological and pathological materials used for analysis in this research were sourced from the International Commission on Missing Persons and are comprised of pathology and excavation reports from Bosnia dating from the period following the war from 1st March 1992 and 14th December 1995. The area of study is shown in the map in Figure Figure 4-1: Map of Western Bosnia with area of research identified (Srebrenica and Lazete)

Figure 4-1: Map of Western Bosnia with area of research identified (Srebrenica and Lazete) (Google Maps 2014)

4.2.1. War in Bosnia

War began in Bosnia in 1992 due to external pressure from both Serbia and Croatia. Both were acting under the motivation of "nationalism", both presenting a territorial claim to the area of Bosnia for their own ends. Slobodan Milosevic, president of Serbia, professed a desire to protect the Serb Bosnians from Islamicism and the government of Croatia wanted to regain territory they believed to belong to Croatia. According to Croatia, the Bosnian Muslims were in fact Croatian. This goes against the Western belief that the fighting within Bosnia was the product of centuries of turmoil between its Muslim and Christian populations when in fact these had been co-habiting comfortably in recent times (Malcolm 2002). The national disputes only reached violence as a result of outside pressures due to the long-standing nationalism push from Serbia and Croatia for Bosnians to identify themselves as either Serbs or Croats. During the period which Bosnia was a part of

Yugoslavia, Bosnians typically associated themselves with one of the two ethnic "fatherlands". This mix of the two was so deeply ingrained in the population, along with a third identity without a "fatherland", that it would take appalling and drastic action to separate them and regain the land (Malcolm 2002).

A large part of the war centred on the propaganda that Muslims were going to begin a Jihad and that there were lists of people whose names were put down for death and rape. As such, using Radio Television Belgrade, local Serbs were convinced that they needed to protect themselves against this Jihad and the Croat Ustaša, the Revolutionary Movement (Malcolm 2002).

In his desire to claim Bosnia's land as territory for the Serbs, Milosevic ordered the destruction of many of the Bosnian towns, which were being protected by Muslim militias. Often, the Serb army would attack a town over the course of several nights, followed by the removal of Muslim men under the guise of displacing them to another location. In 1992, just days before the European Commission recognised the independence of Bosnia; Serbian troops invaded northern Bosnian towns, which were strategically placed to permit the entrance of goods from Serbia. This served also to drive out Bosnian Muslims and to recruit Bosnian Serbs to join the paramilitary units such as Arkan's Tigers, who were involved in the excursions into Bosnian towns. Over the course of five or six weeks, the Serbian military and paramilitaries overtook more than 60% of Bosnian territory. This was due to its highly coordinated and planned attacks using their superior resources (Malcolm 2002). During this year of fighting, the Bosnian forces did not keep up with the Serbians, in terms of armament and manpower. This was the result of sanctions on the former Yugoslavia which were being upheld for Bosnia, preventing the forces to properly acquire the equipment necessary to protect their country against the large-scale capacities of the Serbian troops (Malcolm 2002).

The first half of 1994 was marked by many attempts at making plans for the division of Bosnia. It resulted in an agreement between Croatia and Bosnia, which allowed a division into cantons and for these cantons to hold political power as well as sharing with a centralised government. This plan also included the possibility of having Serb cantons at a later stage but still advocated a division of Bosnia along ethnic lines. A second agreement was proposed, in which half of the Bosnian territory would go to the Serbs and the other to the Federation of Croats and Muslims. The second half of 1994 was marked by the

Bosnian forces making military inroads to fight back against the Serbs, now with the help of the Croats.

The beginning of 1995 was marked by NATO conducting strikes against Serbian military targets. The Serbians retaliated by taking hostage numerous UN soldiers and military observers and placing them hostage at key armament points for the Serbian army, typically chained to the buildings. This resulted in the UN essentially calling off NATO airstrikes. In June, Bosnian forces attempted to break Serbian lines around the town of Sarajevo, in an effort to end the siege which had been going on for many months. This failed and in July, Serbian forces surrounding Srebrenica moved in to seize the town. This was precipitated by the impending arrival of a British and French force to support UN troops and a UN mandate which demonstrated a lack of will to protect safe areas. By 11 July 1995, Srebrenica had fallen to the Serbian troops and the UN peacekeepers could only look on (Malcolm 2002).

Serbian forces began a program of displacement of Muslim men, women and children. It is during the displacement of the Muslim inhabitants of Srebrenica that suspected mass graves were located. Observers from the UN and associated groups were able to discover numerous grave sites, including mass graves identified in aerial and spy photography. These often appeared over the course of a few days. Actually examining these and excavating the graves to find forensic evidence of genocide and war crimes was fraught with problems from lack of infrastructure to threat from Serbian forces (Stover 1998).

This area was heavily contested between the Muslim and Serbian troops. It would become the site of countless atrocities which included the mass displacement of women and children. Muslim men were exterminated brutally in what the Serbians would term "ethnic cleansing" to try and avoid being labelled as perpetrators of genocide (Stover 1998; Malcolm 2002).

4.2.2. Execution points and Mass Graves

The following sites are associated with the mass graves from which the data has been sourced. Below is the historical background of the mass graves and the forensic evidence linking these to the execution points. The sites of the mass graves studied and the execution points associated with Kravica warehouse are shown in Figure 4-2 and Figure 4-3.

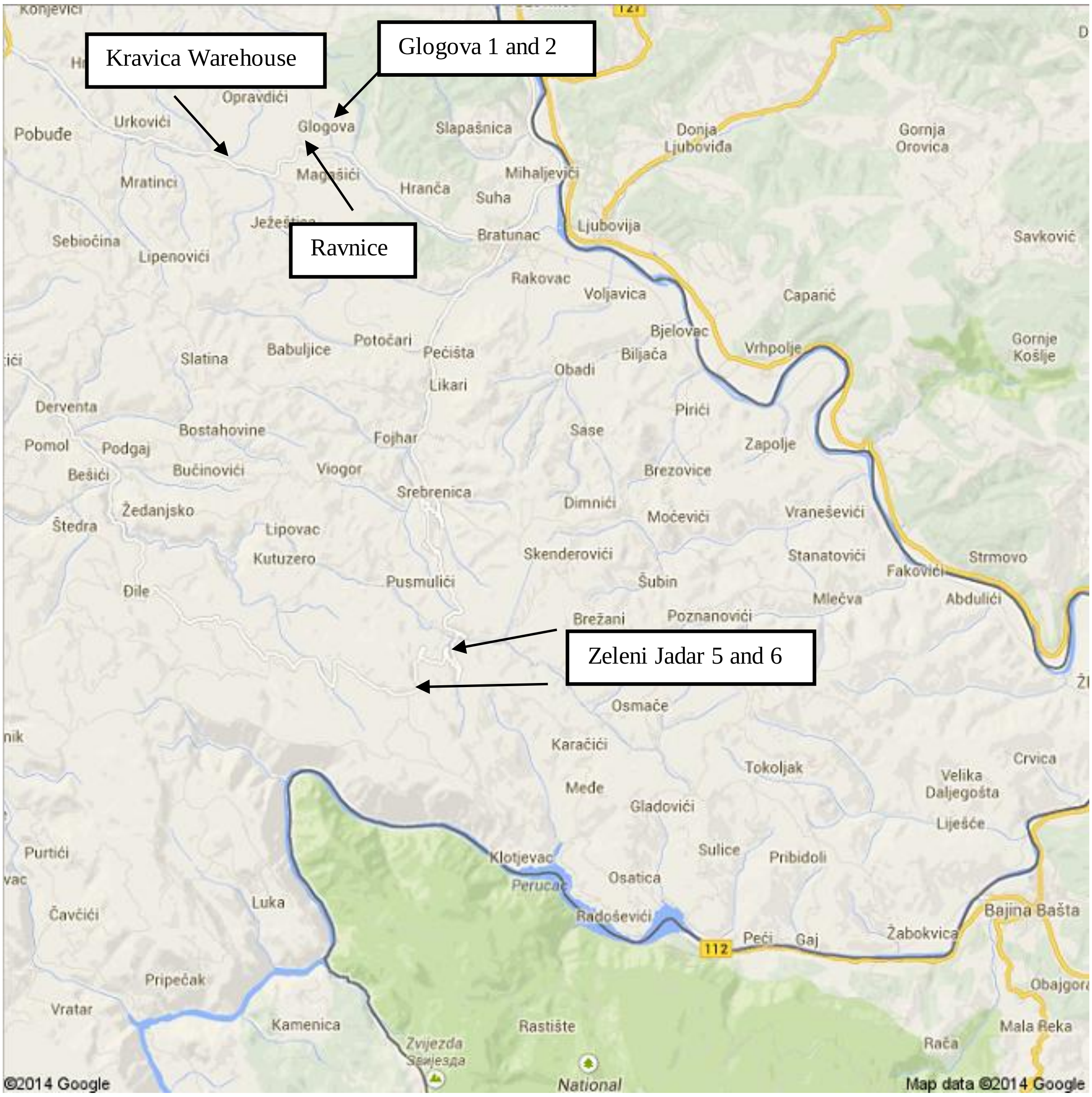

Figure 4-2: Point of execution at Kravica Warehouse and mass graves at Glogova, Zeleni Jadar and Ravnice (Google Maps 2014)

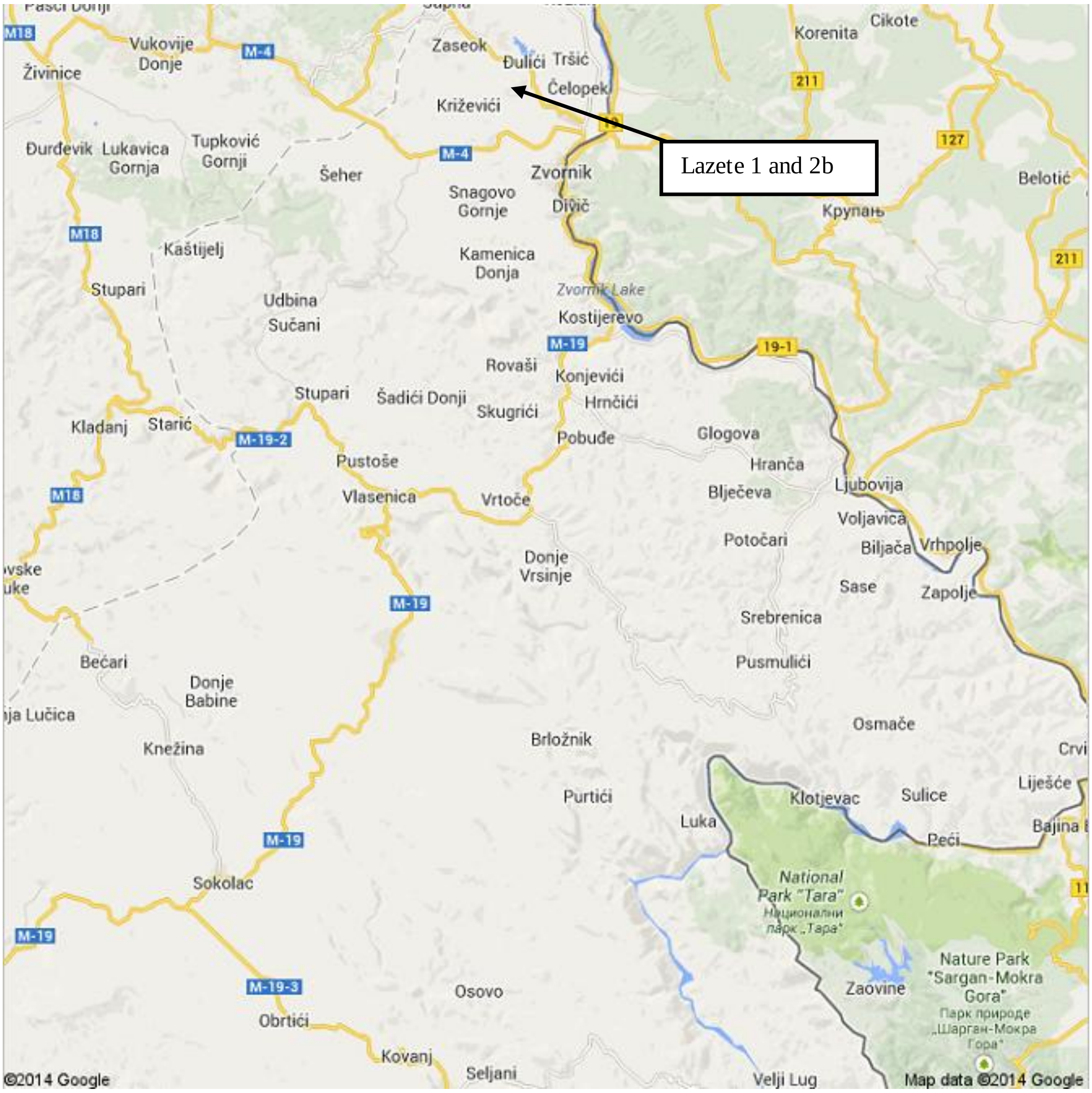

Figure 4-3: Point of execution at Orahovac and mass graves Lazete 1 and 2b (Google Maps 2014)

Kravica Warehouse: Glogova 1 and 2 and Zeleni Jadar 5 and 6

The case presented is an ongoing human rights and genocide case involving crimes committed during the Bosnian conflict in 1995. The case involves remains from the massacre at the Kravica Warehouse located in Kravica, Bratunac County. It was alleged that on 13 July 1995, between 1000 and 1500 men were taken to the Kravica Warehouse, placed in two rooms and killed using machine guns, automatic rifles, grenades and other forms of explosives fired through doorways from the front of the building (2000). According to two witnesses having survived the attack, heavy equipment was used to break down the walls and doors of the warehouse. Remains were carried away and dumped into graves approximately one kilometre from the warehouse (Anon. 2000). This site is named Glogova and includes two areas, Glogova 1 and Glogova 2. This site was excavated during 1999, 2000 and 2001. This gravesite is a primary grave (Manning 2003), a site where the remains were interred following the incident and never moved. A second grave at this location was also linked to the Kravica Warehouse, Glogova 2.

The Glogova grave sites did not remain undisturbed and it has been established that remains from Glogova were subsequently reburied at the Zeleni Jadar grave sites. Zeleni Jadar 5 and Zeleni Jadar 6 have been linked to the Glogova graves through matching artefacts, soil and pollen samples as well as shell casings (Manning 2003). Artefacts, such as pieces of steel reinforced masonry, steel and concrete doorframes, motor vehicle parts (the warehouse was used to store these), grenade levers along with shrapnel, were located in these primary graves at Glogova and subsequent analysis demonstrated the link between both Glogova 1 and Glogova 2 and the warehouse in Kravica (Manning 2003). Forensic investigation of samples from the burnt areas of the warehouse demonstrated the presence of TNT (2000) and the East, South and West walls of the warehouse showed visual evidence of explosives damage (Manning 2000). This included impact sites with blood and tissue spatter, areas of explosive detonation creating impact defects in the wall material and areas marked with suspected explosive residue (Manning 2000).

Ravnice

This complex of two graves, designated RV01 and RV02 and treated as one mass grave, was located near the Glogova graves and the Kravica Warehouse (Manning 2007). This mass grave differs by being a surface deposit with 175 bodies and 324 body parts scattered on a slope which leads to a stream. The surface deposits were found over a large area (Clark 2001). Evidence recovered included building materials such as plaster and concrete which when analysed were found to be indistinguishable from those in the Glogova 1 and 2 graves as well as the Zeleni Jadar 5 and 6 graves. These pieces of evidence were demonstrably linked to Kravica Warehouse, which is deemed as an execution points for these three sets of mass graves (Manning 2007).

According to the 2007 report by Manning, a total of 187 DNA identifications have been made from the skeletonised remains found at the Ravnice 1 and 2 surface deposits (2007). Anthropological and pathological analysis yielded the following demographic results. 170 bodies were identified as being male along with 5 remaining undetermined. The age range was between 8 to 90 years, with 36 being less than 25 years old and 14 individuals aged 17 or younger. 161 individuals died from gunshot wounds and 14 from an undetermined cause of death. The specific demographics of the cases included in the analysis will be discussed subsequently in this chapter.

Lazete 1 and Lazete 2B

The graves designated as Lazete and Lazete 2B are located in the Orahovac area. These sites have been found to be both execution and primary burial sites, albeit disturbed in places (Manning 2000). The sites were located through aerial imagery, indicating that the graves had been dug between 5 July 1005 and 19 July 1995. Lazete 1 was excavated over the course of the summer in 2000. Lazete 2 is located along railroad tracks and a dirt road which leads to the Lazete 1 grave. Evidence has linked these graves to the ones found at Hodzici Road (3, 4 and 5). This was done through the identification of piping which had been in the field through Lazete 1. During the creation of the grave, the pipe had been cut and a portion of it found in the secondary Hodzici Road grave (Manning 2000).

The Lazete 1 grave was found contain 130 individuals, 129 of whom were male (with one of undetermined sex). Blindfolds were found with 92 individuals, as well as associated in 8 more cases. These resembled those found at Lazete 2 and the associated Hodzici Road secondary mass graves (Manning 2000). The ages range from 12 to 25+ and 125 individuals have a cause of death listed as gunshot wound. Additionally, ligatures were found on 3 individuals (Manning 2000).

Examination of blindfolds found at the nearby Grbavci School identified these as matching the blindfolds found in the Lazete 2 and Hodzici Road graves. This also corroborates a witness account who stated that he was blindfolded and detained at this location during the Krstic trial (Manning 2000). Shell casings from Lazete 2 were also forensically associated with those collected at the secondary Hodzici Road Sites.

Specifically, the Lazete mass graves used in this research are Lazete 1 and Lazete 2B. The Lazete 2 grave is comprised of Lazete 2 A, B and C. The Lazete 2B grave was excavated in 1996 by Physicians for Human Rights with the ICTY (Manning 2000) and the results of the pathology and anthropology analysis are used in this research. The Lazete mass graves were included in the analysis to serve as comparators to those associated with the Kravica Warehouse primary execution point and its primary and secondary mass graves. To adequately assess any differences in the patterns of trauma, comparison with mass graves known to contain remains of those having been killed by gunshot at a different location is employed.

4.2.3. Background of data used

The Bosnia materials are composed of extensive records curated by the International Commission on Missing Persons and include excavation reports and photographs, autopsy reports and photographs as well as materials which are given to the International Criminal Tribunal for the Former Yugoslavia. Additional materials were directly provided by the ICTY to the ICMP and shared with the researcher.

Acquisition

The materials were acquired during a period of five weeks in summer 2012 when the researcher had an internship at the International Commission on Missing Persons in Sarajevo, Bosnia and Herzegovina. During this period, the materials were examined and organised by case to facilitate the future analysis by the researcher and to provide these back to the ICMP. The materials were digitised and permitted the easy organisation for future analysis.

Permissions

The researcher was permitted by the ICMP to possess the materials during the period of the project and is required to relinquish possession once this is complete. The data remains the possession of the ICMP and anything published in the thesis can only be comprised of raw data (as coded anonymously for analysis by the researcher). Photographs may only be included if these have been previously used in reports that have been entered into the courtroom procedures of the ICTY. This is because of ongoing court cases and confidentiality issues tied with this. No materials are used without the permission of the Deputy Director of forensic science, anthropology and archaeology at the ICMP, Mr. Ian Hanson.

4.2.4. Samples

Data from five mass graves in Bosnia are used. The five sites are Glogova 1 and 2, Zeleni Jadar 5 and 6, Ravnice, Lazete and Lazete2B.

Lazete and Lazete 2B are treated separately, having been excavated during different years and by different organisations, Physicians for Human Rights and subsequently the ICMP.

Demographics

The samples are composed entirely of male remains. Ages have been determined by previous anthropological examination detailed in the pathology reports, along with biological sex. Both age and biological sex were determined by the anthropologists under the direction Jose Pablo Baraybar. Table 4-1 outlines the age ranges for each of the individual mass graves, including those excavated by Physicians for Human Rights and the International Commission on Missing Persons.

Table 4-1: Age ranges of remains in individual grave samples.

Grave	Age range
Glogova 1	12 to 75
Glogova 2	12 to 71
Zeleni Jadar 5	13 to 25+
Zeleni Jadar 6	8 to 65
Ravnice	8 to 25+
Lazete	15 to 25+
Lazete 2B	13 to 70

Glogova 1 and 2

The materials used from the Glogova mass graves are composed of 276 cases, all of which are male. Within these, the cause of death is listed as one of 4 options in the pathology reports (gunshot wound, blast injury, gunshot wound and blast injury and undetermined). Table 4-2 represents the distribution of cause of death.

Table 4-2: Distribution of the cause of death in the Glogova 1 and 2 graves, including blast injury, gunshot wound, the combination of blast injury and gunshot wound and unascertained causes of death.

		Frequency	Percent	Cumulative Percent
Cause of Death	Blast injury	45	16.3	16.3
	Gunshot wound	162	58.7	75.0
	Blast injury and gunshot wound	16	5.8	80.8
	Unascertained	53	19.2	100.0
	Total	276	100.0	

Additionally, the cases selected were composed of those which had a complete body or body parts with identified trauma. 80.8% of cases selected were those with a complete body, as determined by the pathologist and checked by the researcher. Additionally, the presence of physical evidence was also used to corroborate the cause of death determination from the pathologist and anthropologist, presented in

Table 4-3: Glogova- Presence of physical evidence associated with the remains. Physical evidence is remains of explosive materials such as grenade casings or bullets, found within and associated with the remains..

Table 4-3: Glogova- Presence of physical evidence associated with the remains. Physical evidence is remains of explosive materials such as grenade casings or bullets, found within and associated with the remains.

		Frequency	Percent	Valid Percent	Cumulative Percent
Physical Evidence	Absent	82	29.7	31.7	31.7
	Present	177	64.1	68.3	100.0
	Total	259	93.8	100.0	
No information	System	17	6.2		
Total		276	100.0		

Zeleni Jadar 5 and 6

The cases from Zeleni Jadar 5 and Zeleni Jadar 6 number a total of 12 cases which were selected as their cause of death were listed as blast injury. These were the only cases selected as the number of blast injury cases overall in these graves was small whilst those with gunshot wound or unascertained causes of death were much more frequent. Additionally, as these were a secondary grave from Glogova and the condition of the remains (fragmented and commingled) made trauma assessment more complex it was deemed best to use these cases only to augment the blast injury assemblage. Of the 12 cases with cause of death listed as blast injury, 58.3% were without a complete body (Table 4-5), composed of limbs or small groups of bones. However, in combination with the information in the pathology reports, anthropology reports and photographs, 91.7% (11 cases) were associated with physical evidence corroborating the diagnosis for cause of death (Table 4-4). These cases were concluded as having blast injury and being included in the sample because of the corroborating evidence.

Table 4-4: Presence of associated physical evidence. Physical evidence is remains of explosive materials such as grenade casings or bullets, found within and associated with the remains.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absent	1	8.3	8.3	8.3
	Present	11	91.7	91.7	100.0
	Total	12	100.0	100.0	

Table 4-5: Zeleni Jadar- Presence of a complete body, rather than individual body parts such as a sole limb.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absent	7	58.3	58.3	58.3
	Present	5	41.7	41.7	100.0
	Total	12	100.0	100.0	

Ravnice

The cases from the Ravnice 1 and Ravnice 2 are treated as one data set and combined together, as these were excavated at the same time and by the same group, the ICMP. Also, these remains were from the same case, killed at the same time and disposed of in two sites near each other. The case number differentiates the two by beginning either with RV01 or RV02. From these mass graves, 162 cases were selected, all with the cause of death listed as gunshot wound or unascertained in the pathology reports. The frequency of each of the causes of death is presented in Table 4-6: Ravnice- Causes of death in Ravnice 1 and 2 graves, including gunshot wounds (GSW) and unascertained cause of death.

Table 4-6: Ravnice- Causes of death in Ravnice 1 and 2 graves, including gunshot wounds (GSW) and unascertained cause of death.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	GSW	146	90.1	90.1	90.1
	Unascertained	16	9.9	9.9	100.0
	Total	162	100.0	100.0	

As with the previous two mass graves, some of the remains were incomplete bodies. This was due to the scattering of the remains on the surface, both from being dumped down a slope (causing further movement when skeletonised) or potential animal activity. Despite this, 68.5% of the cases used in the analysis were composed of complete bodies (see Table 4-7).

Table 4-7: Ravnice- Presence of a complete body

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absent	51	31.5	31.5	31.5
	Present	111	68.5	68.5	100.0
	Total	162	100.0	100.0	

Presence of associated physical evidence corroborating the cause of death determined by the pathologist was also noted for the remains from Ravnice 1 and 2. This mass grave had a higher number of cases that had no associated physical evidence (48.1%), possibly due to the nature of the remains being spread on a surface and down a slope. 84 cases did have associated physical evidence (see Table 4-8: Ravnice- Presence of associated physical evidence).

Table 4-8: Ravnice- Presence of associated physical evidence. Physical evidence is remains of explosive materials such as grenade casings or bullets, found within and associated with the remains.

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absent	78	48.1	48.1	48.1
	Present	84	51.9	51.9	100.0
	Total	162	100.0	100.0	

Lazete

The Lazete graves are treated as two different graves due to the excavations being undertaken at two different times and by two different organisations, rather than a geographic separation. As such, the data has been collected and compiled separately for each grave. Remains from Lazete 2B were excavated and analysed by Physicians for Human Rights in 1996. Demographics for these are presented in the following section.

The data from Lazete 1 is composed of 97 cases. The cause of death for all cases is listed as gunshot wounds in the pathological reports. The researcher found no reason whilst examining the reports and the autopsy photographs to disagree with these findings as clear morphological characteristics of gunshot wounds were seen on the remains. As with the other sites, the presence or absence of a complete body was noted and found to be present in 91 cases (see Table 4-9). This was used to determine the inclusion of cases in the sample.

Table 4-9: Lazete 1- Presence of a complete body.

Complete Body		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Absent	6	6.2	6.2	6.2
	Present	91	93.8	93.8	100.0
	Total	97	100.0	100.0	

Physical evidence was also noted to confirm the cause of death listed in the pathology reports. Of the 97 cases included in the analysis, 80.4% (78) had associated physical evidence, such as casings in the remains and associated, and 19.6% (19 cases) did not. This continues the trend in all the mass graves selected for study, with exception of Ravnice 1 and 2.

Lazete 2B

The second Lazete mass grave included in the sample is Lazete 2B. This is indentified distinctly from Lazete 1 due to the temporal separation of the excavation, conducted by a different organisation (Physicians for Human Rights). The data from the Lazete 2B is collected from the pathology reports and autopsy photographs from the Physicians for Human Rights who conducted the investigation in 1996. Lazete 2B is composed of 37 cases, all of whom have the cause of death listed as gunshot wounds in the pathology reports. The researcher found no reason whilst examining the reports and the autopsy photographs to disagree with these findings. Presence of a complete body was also noted and was found to differ from the Lazete 1 grave. In Lazete 2B 54.1% (20 cases) had a complete body while the remainder were fragmentary (45.9%, 17 cases), however these could still be employed as part of the sample. Associated physical evidence was also examined from the Lazete 2B cases and was present in 43.2% of cases (n=16) and absent in 56.8% of cases (21 cases).

4.3. Canadian World War I circumstances of death records

One of the aims of the study was to compare the patterns of trauma from the Bosnia cases with various other sources to aid in the identification and recognition of injury patterns in blast related cases. Specifically, examining the question of a difference between combat and non-combat trauma patterns would require comparison with contexts that can be deemed similar to those found in the Bosnian sample. Basic comparison with published data from previous conflicts comes with issues such as a difference in the weaponry used as well as protective methods. In the modern conflicts, body armour is commonly used by soldiers. Whilst comparing the patterns of trauma from these situations is still necessary and adds to anthropological knowledge, a source of data from a conflict which did not use body armour would be necessary. As such, the researcher found information publicly available regarding the injuries in the war dead from the Canadian Forces during World War One, stored in electronic archives (www.collectionscanada.gc.ca). These soldiers did not employ body armour and as such the clothing would be more similar to that worn by those from the Bosnia sample. Papers written focusing on blast injury were rare for World War One and it was chosen to use the data directly from the records so that it may be processed in a way that would lend itself easy analysis by the researcher.

4.3.1. Background to the sample

The samples include soldiers who were killed in action in Ypres, Vimy, Passchendaele and other locations in the Somme. The following outlines briefly the background to these battles.

Second Battle of Ypres

The 1st Canadian Division arrived in Europe in October 1914. Composed of mostly militia reserve men, they numbered 25,000. Between February and March 1915, 18 000 men from the 1st division went to Fleurbaix. In mid-April they moved to the Northeastern sector of the Ypres Salient.

Ypres is located in the Salient region and was considered to be one of the most important and contested areas of the Western front. Half of the Allies' casualties were at the Western front. This was a difficult area to defend, as the German troops were located on three sides. The Canadians were entrenched a mere few hundred yards from the German trenches (Freeman and Nielsen 1999).

By the 25th of April, many lives were lost in the renewed efforts to maintain positions and not give up any territory to the Germans. They were forced to give up the town of St-Julien and half of Gravenstafel ridge had fallen to the Germans. This forced the Canadian withdrawal and the need for relief in the form of British and Indian troops. The Canadians remained in the Salient whilst their relief attempted to regain the losses. They were at a disadvantage and were not able to regain. The Germans attempted to take Frezenburg Ridge but failed on May 8th. The Canadians held their ground and continued to protect the British flank. 1500 Canadians died around St- Julien (Freeman and Nielsen 1999).

By the official end of the Second Battle of Ypres on May 25th, 6000 Canadian troops had lost their lives.

The Somme

In the summer of 1916; the Canadians were ordered down from Flanders to relieve the British in the Somme, who had experienced the highest number of casualties in a single day. The Canadian troops headed towards Courcelette and made unprecedented gains during this time. Battle strategy then involved the increasing use of shells but was proved to be ineffective and the casualty number kept growing. Finally, at the end of October, the Canadian troops took the Regina trench and its German soldiers. This marked the end of involvement in the Somme with the ultimate result being a gain of only a few thousand yards of land.

At the Somme, the Canadians lost 24,029 soldiers.

Vimy Ridge

The most important battle of World War One for the Canadian troops was the battle of Vimy Ridge, where for the first time all four Divisions fought as one. The Germans had a two year head start at Vimy Ridge and had been tunnelling during this time, building fortifications. They occupied the top of the Ridge and its Western slopes, which the Allies wishes to regain (Freeman and Nielsen 1999).

Over the course of the battle, the 4th Division was tasked with taking two important targets, Hill 145 and the Pimple. These were the highest point on the Ridge and had strong fortifications. On April 12th, 1917 the Pimple was taken and made the advance the deepest British advance in two and a half years. The Canadians lost 3,598 men (Freeman and Nielsen 1999; Christie 2002).

Passchendaele

Passchendaele that was the next large scale advance. This was located in the Northern part of the Ypres Salient and would become known as the Third Battle of Ypres (Freeman and Nielsen 1999). A second attack was undertaken a few days later following an artillery barrage (Freeman and Nielsen 1999).

The Canadians took Passchendaele village and cleared the ridge by November 10th, but had lost 15, 654 men during the battle.

The Canadians continued to figure prominently in the Allies advance, taking Amiens, Arras and Cambrai. They ended the war by taking Mons in Belgium, liberating it from the

Germans on November 11th, Armistice Day. Over the course of World War One, Canadians troops lost nearly 65,000 soldiers and officers.

4.3.2. Nature of the sample

The records of deaths from the First and Second World War are held by Library and Archives Canada. These are kept in one series (Accession RG 150, 1992-93/314) composed of 302 volumes. Volumes 145 to 238 contain the Circumstances of Death binders (also known as the "Brown Binders") for World War One. These can be accessed electronically at http://www.collectionscanada.gc.ca/microform-digitization/006003-110.02-e.php?&q2=28&interval=50&sk=0&PHPSESSID=esvtc19976e0v4bc46h9rnmuf0

Each member of the Canadian Expeditionary Force member is given a two page document to note the following information:

* Service number
* Rank
* Name (Surname and Christian Names)
* Unit or Ship
* Date of Casualty
* Headquarter File Number
* Religion
* Circumstances of casualty
* Name, Relationship and Address of Next of Kin
* Location of Unit at Time of casualty
* Cemetery
* Location of Cemetery
* Grave Location and Information

During the war, these records were compiled by the Records Office of the Overseas Ministry. The burial information was shared with the Militia and Defence Headquarters. This information is now kept by the Commonwealth War Graves Commission. Historical military service records were transferred over to what became Library and Archives Canada in 1971. These records are now available in .jpg and .pdf format from Library and Archives Canada (www.collectionscanada.gc.ca).

For the purposes of this thesis, the microforms available online were examined to collect data. These are arranged in 94 online volumes, which each contain a different number of pages but are arranged in alphabetical order.

Each record was examined for evidence of blast trauma such as that received from a mortar shell. In the case of mortar shells, shrapnel trauma is considered blast trauma as well for this study as this is a prominent injury from blast, representing secondary blast trauma. Each case file is noted according to the service number of each soldier. Area of trauma is noted as present or absent, as well as which side on the body. The sample from the World War One files is composed of cases which are listed as having died from either blast injury or gunshot wounds. This enables comparison with the various sources, such as the results of the Bosnia analysis as well as the clinical data which presents patterns of gunshot wounds and blast injury from various modern conflicts and terrorism related activities.

The sample is composed of a total of 230 cases. Of these, 89 have gunshot wounds and 141 have blast injuries. The patterns of trauma in this sample are discussed in 6.1.2, along with the results of all analyses.

5. Methods

To determine if there are patterns of injury that can indicate blast injury in the human skeleton, statistical analysis of the data is undertaken. The methods were selected to reflect inductive reasoning, to examine patterns and indicators which determine the nature of the trauma seen in the assemblage. Descriptive statistics were undertaken along with binary cluster analysis, multiple correspondence analysis and finally moving to probabilistic modelling using binary logistic regression analysis.

5.1. Rationale

This research aims to provide information about blast injury in anthropological contexts through the examination of assemblages from the Kravica warehouse related cases from Bosnia and Herzegovina. The identification and differentiation of blast injury has previously solely been examined in the clinical context. This is problematic for anthropology, a discipline where the possibility of encountering this type of trauma in a variety of emerging contexts has increased recently, from criminal investigations, to human rights work and terrorism related incidents.

The lack of knowledge regarding these types of injuries in anthropology makes it important to begin the exploration of the patterns of injury that can be expected when dealing with these types of injuries in skeletonised remains. An example of this can be seen in the court proceedings of, where defence attorneys argued that the injuries seen in the human remains from the Kravica warehouse were combat-related. No assertion could be made that this was or was not the case beyond personal experience of the pathologist, highlighting an area where further research needed to be undertaken to answer this question.

With these goals it was decided to approach the problem of identification and differentiation of blast injury by comparing the known cases of blast injury from the Bosnian data sample to those of a more documented type, gunshot wounds. Direct comparison of the patterns within the sample was undertaken to assess the similarities or differences using statistical methods, to permit quantification and reproducibility of the results. Additional comparison was undertaken to address the issues which have been highlighted in the court cases, by comparing the identified patterns in the Kravica sample with those from other combat contexts. Finally, direction on the identification of blast injury is addressed and its potential for court proceedings and future anthropological investigation is explored as the lack of guidance on this has been identified in anthropology.

5.2. Epistemological and methodological framework

The methods selected for the study can be classified theoretically as part of inductive reasoning. This methodology can be applied to scientific problems and is central to categorization. In this study, categorization of the samples and their subgroups is an important exercise to determine characteristics of blast injury which could serve as indicators for future identification of trauma in assemblages.

Induction comprises of identifying perceptual similarity, taxonomic relations and premise monotonicity. Perceptual similarity occurs when the base "object" (in this study, individuals) overlaps with the target, resulting in the inference that these have the same properties. This can be used at the sample or individual level to group variables or cases together to identify patterns of injury. Taxonomic relations indicates that members of closely related categories will share properties and that premise monotonicity will infer that the more categories (or individuals) sharing properties will also share these with the larger group (or population).

Using induction, one can draw relations between the characteristics and the individuals of the samples to infer properties of the general group from which they have been sampled. Specifically this is termed category-based induction and "may be guided by and reflect categorical relationships" (Heit and Feeney 2007).

The chosen epistemology is appropriate as it takes into account that this project aims to develop guidance on the identification and differentiation of blast injury. By employing inductive reasoning, methods selected are those which can help to identify the characteristics associated with blast injury, from a sample of known trauma. This reflects the bottom up approach associated with inductive reasoning, where the researcher starts with a sample (the individuals from the Kravica warehouse sample) and seeks to infer properties of a group (skeletonised remains with suspected blast injury) (Heit 2007).

Employing an inductive epistemology has implications for research design. Beginning with the individual sample permits the formulation of hypotheses regarding the nature of blast injury, followed by the differentiating patterns between the blast injury and gunshot wound samples and subsequently leading to probabilistic modelling which tests the predictive characteristics of a sample.

According to Harman and colleagues (2007), inductive methods are used to find rules for classification, which is one of the main objectives of this study. Using this framework the researcher can apply statistical methods to extrapolate group characteristics to an unlabeled case. This requires the combination of the inferential methods with other methods to build a hypothesis fitting the data which can subsequently be tested. Inductive theory in statistics includes methods such as nearest neighbour induction, whose principle is applied in cluster analysis, one of the techniques being employed for classifying cases within and between samples (Harman et al. 2007). Under this principle, cases are classified into groups based on theory that the nearest neighbour (with similar characteristics and properties) belongs to the same group.

To further assess the validity of the conclusions made from the cluster analysis, multiple correspondence analysis is employed, a second exploratory method which seeks to classify cases and variables to generate conclusions and hypotheses regarding the data collected. This method is again one of induction and is well suited to the grounded theory framework (Strauss and Corbin 1998; 2004; Anon. 2008), which stipulates that theories must be built from the examination of the data and their relationships. Employing multiple correspondence analysis satisfies this condition, whilst also scaling the variables examined to note the relationship between these and with the cases and samples examined. This is also a mixed methods approach, combining the qualitative data from the reports with quantitative outputs that examine the strength of these associations and graphically illustrates the relationships on principle axes that are easy to visualise for the purposes of theory building.

Finally, testing of the hypothesis can be undertaken through statistical analysis to build a model using binary logistic regression. This model quantifies the relationships between variables and their strength as well as generating a formula that can be used to ascribe group to a specific combination of outcomes for the variables. This approach uses a probability model which corresponds to one of the basic tenets of induction, using probabilities to determine the credibility of conclusions. Also, by employing a probability test such as the binary logistic regression selected, the body regions which differentiate between the two causes of death are tested for their accuracy in predicting cause of death. This can lead to further refinement of the interpretation and application for future guidance.

Using an inductive model of epistemology, this research achieves the development of characteristics to aid in the identification and differentiation of a previously under-represented type of trauma in anthropological contexts.

5.3. Data preparation

During the data acquisition phase, it was important to assess the presentation of the data and what could potentially be done undertaken. The original format of the data was textual along with photographic evidence. As this type of examination of such data has not been previously undertaken, different approaches were explored. Initially, a simple system of body regions was developed, based on the Rule of Nines employed in medicine for the assessment of burns to the skin (Lund and Browder 1944). The body regions described for statistical analysis were the skull, vertebrae, upper limb, torso, pelvis and lower limb. This coding system was employed during the first phase of the project, which included the original data as provided by the former Chief Pathologist of the ICTY, Dr. John Clark. This methodology is also employed with the data collected from the World War One files.

Each of the body regions was then assessed for presence or absence of trauma, which for the purposes of statistical analysis were denoted as the number 1 (absence) and 2 (presence). This system had to be altered at a later date to accommodate the need for certain statistical tests to be undertaken with a binary coding system based on 0 as the indicator of absence and 1 for presence.

5.3.1. Bosnia

Subsequently, additional data were provided through an agreement with the ICMP, which permitted clarifying of the body region variables to include more information, refining the patterns identified in the samples. The detail included in the pathological reports includes identification of the anatomical regions injured, whether this included bone (in the skeletonised cases) as well as soft tissue injury. Only the data regarding skeletal injuries was employed in the study. Table 5-1-: Body Region Variables gives an overview of the body regions which were created for the analysis. These regions were chosen to permit breaking down the areas of the body into the sections which were used to describe the trauma to the body regions in the pathology reports received from the ICMP.

Table 5-1-: Body Region Variables with the associated affected bones described and siding variables explained.

Body Region (Variable)	Bones affected
Neurocranium	Frontal, Parietal, Temporal, Occipital
Maxillofacial	Maxillae, Palatines, Vomer, Inferior nasal conchae, Ethmoid, Lacrimals, Nasals, Zygomatics, Sphenoid
Mandible	Mandible
Vertebrae	Hyoid, Cervical, Thoracic, Lumbar, Sacral vertebrae and coccyx
Left Shoulder Girdle	Left clavicle, Left Scapula
Right Shoulder Girdle	Right clavicle, Right Scapula
Left Upper Arm	Left Humerus
Right Upper Arm	Right Humerus
Left Forearm	Left Radius, Left Ulna
Right Forearm	Right Radius, Right Ulna
Left Hand	Left carpals, Left metacarpals, Left hand phalanges
Right Hand	Right carpals, Right metacarpals, Right hand phalanges
Left Ribs	Left ribs and left half of sternum
Right Ribs	Right ribs and right half of sternum
Left Pelvis	Left Pelvis
Right Pelvis	Right Pelvis
Left Femur	Left Femur
Right Femur	Right Femur
Left Tibia and Fibula	Left Tibia and Fibula
Right Tibia and Fibula	Right Tibia and Fibula
Left Foot	Left tarsals, Left metatarsals and left foot phalanges
Right Foot	Right tarsals, Right metatarsals and Right foot phalanges
Left	Bones of the left side
Right	Bones of the right side
Bilateral	Bones affected on both sides
No Side	Bones which cannot be sided (i.e. skull, vertebral column)

A case number variable was also created; using the case numbers assigned during excavation and used in the pathology reports. No names were used. The format of the case number assigned was a two letter designation indicating burial location, followed by two numbers indicating the grave number. To designate the specific case number, three numbers are used as assigned by the field team when excavating the remains. This is followed either by the designation B (complete body) or BP (body part). The coding system for each case number is shown in Figure 5-1: Designation of case numbers.

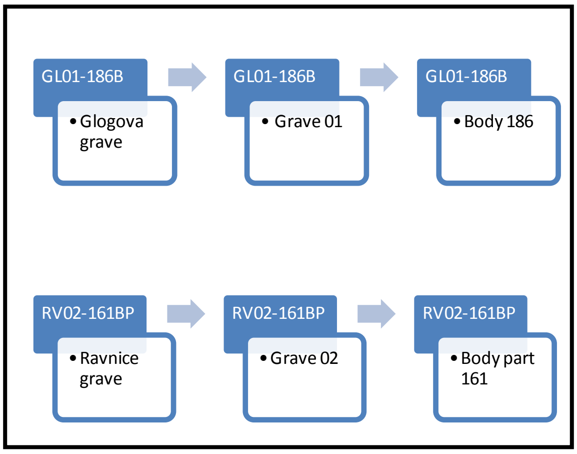

Figure 5-1: Designation of case numbers

Data Coding- Bosnia

The data are coded using the outcome of absence (1) or presence (2) for each variable. Additional variables have also been used to describe the data. This includes a site code, a cause of death variable, an absence or presence of associated physical evidence variable and an absence or presence of a complete body variable. The associated coding for these variables is seen in Table 5-2- Variable coding for non-body region variables.

Table 5-2- Variable coding for non-body region variables, including the grave site, cause of death, presence or absence of associated physical evidence and presence or absence of a complete body/skeleton.

Variable	Outcome coding
Site	1= Glogova 2= Zeleni Jadar 3= Ravnice 4= Lazete 5= Lazete 2B
Cause of Death (COD)	1= Blast Injury (BI) 2= Gunshot Wound (GSW)
Physical Evidence (PhysEvid)	1= Absent 2= Present
Body	1= Absent 2= Present

To code each case entry in the database, the pathological report is examined alongside the autopsy photographs for every case included. Trauma described by the pathologist is identified and confirmed by examining the autopsy photographs. Trauma is only included when there is consensus between the report and the photographs as determined by the current researcher. This is done by confirming the presence of perimortem skeletal trauma, using the criteria outlined in Sauer (1998). If there is any ambiguity as to the nature of the trauma, the case is not included in the research. Only skeletal trauma is included.

Each case is represented by one row in the data editor. An example of the layout of the data file is found in Table 5-3. For the purposes of analysis, specific cases were selected; those which had the causes of death listed as blast injury or gunshot wounds in the pathological reports. No cases of unascertained death or combination of blast injury and gunshot wounds were employed as the purpose of the analysis was to differentiate between these two types of trauma.

Table 5-3: Example of the layout of coded data. Each column represents one variable. Each row represents one case.

Case#	Site	COD	PhysEvid	Body	Neurocranium	Maxillofacial	Mandible	Vertebrae	LShoulder	RShoulder	LUpArm	RUpArm	LForearm	RForearm	LHand	RHand	LRibs	RRibs	LPelvis	RPelvis	LFemur	RFemur
GL01/186B	1	1	2	2	1	1	1	2	1	2	2	1	1	1	1	1	2	2	2	1	1	1
GL01/214B	1	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
GL01/38B	1	2	2	2	1	1	1	2	2	2	1	1	1	1	1	1	2	2	1	1	2	1
GL01/205b	1	2	2	2	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	2	1	1
GL01/029B	1	2	1	2	1	1	1	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1
GL01/060BP	1	2	2	1	2	1	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GL01/068BP	1	2	1	1	1	1	1	1	2	1	1	1	1	1	1	1	1	2	1	1	1	1
GL01/069B	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GL01/072B	1	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	2	1	1	1	1	1
GL01/131B	1	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1	1

5.3.2. World War One

The data in the Canadian soldier casualty files is not as detailed as the Bosnia pathology reports in terms of trauma assessment. Initially, the intent was to compare directly the patterns in the casualties from World War One to those from Bosnia. Due to the format of the information and the differences in detail between two samples, the Bosnia sample was aggregated for comparison. An examination of the two samples using prevalence dated coded with a smaller number of variables was accomplished.

Coding- World War One

The data is coded in the same manner as the Bosnia data, using a dichotomous outcome (presence/absence) over a smaller number of variables. This coding corresponds to the body regions presented in the clinical literature.

The layout of the data is similar to the Bosnia data's layout in SPSS (see Table 5-3) however, with fewer variables. The variables employed for this data set are outlined in Table 5-4-World War One data body region variables. These were selected as they reflect the typical body regions which were recorded in the documentation as well as in the clinical literature.

Table 5-4-World War One data body region variables

Variable	**Body region and associated bones**
Body region 1	Skull (bones of vault and mandible)
Body region 2	Vertebrae (if specifically identified in the report)
Body region 3	Upper limb (humerus, radius, ulna and hand)
Body region 4	Torso (shoulder girdle, ribs, manubrium, sternum and clavicle)
Body region 5	Pelvis (pelvis, sacrum and coccyx)
Body region 6	Lower limb (femur, tibia, fibula, foot)

5.4. Methods selection

The following section outlines the methods selected and the reasoning behind their application in the context of the aims of the research.

5.4.1. Statistical versus experimental methodology

For this research, statistical methods were chosen to conduct the analysis of the data. Initial experimental work was explored but complexities involving legal and practical issues would be difficult to overcome. Although collaborations were agreed with a Ministry of Defence munitions disposal team which involved the use of deer proxies, these did not work out.

Due to this a differing source of data was sought and the collaboration with the International Commission on Missing Persons was established, permitting access to the sole archaeological source of skeletonised remains of cases with known blast injury. While keeping in mind one of the problems with the identification of blast injury in skeletonised remains, such as was presented in the ICTY court proceedings, a statistical approach was evaluated. This methodology quantifies differences and similarities in a manner that can presented based on a probability and can give a standard error or deviation for the results which are robust and better accepted in court proceedings. This is important to ensure the scientific presentation of evidence in court, which has been discussed at length in previous research (Grivas and Komar 2008; Christensen and Crowder 2009). A second consideration was that no previous work had been done on the identification and differentiation of blast injury and describing this type of trauma in an anthropological context, with a unique case study, was determined to be an appropriate first step.

5.4.2. Describing the data

The data collected represents nominal data, which is non-numerical data. The variables examined are categorical with an outcome indicating presence or absence of trauma in the particular region of the body. Methods for analysis must be selected from those capable of handling such categorical data and remain limited. To begin, descriptive statistics are undertaken to count frequencies associated with each variable. These can be transformed to percentages, lending them to easy comparison with the data previously published in the medical literature and with the data from the World War One sample.

5.4.3. Exploring the data- patterns and relationships

As this research project aims to develop potential methodologies for the analysis of specific trauma, exploratory methods are used to analyse the data to determine if any relationships exist between the cases and the variables which can subsequently be examined with more detail. Graphical and multivariate methods permit the reader to observe the relationships between cases and variables in a more directly observable way rather than with numbers found in contingency tables. These methods include those employed for exploration of the current data, cluster analysis and multivariate correspondence analysis.

Multivariate statistics

When using categorical nominal data with a dichotomous outcome, methods for analysis can be limited. Most anthropological studies currently approach this type of data in trauma studies using simple pairwise χ^2 tests. Representing relationships between two cases, variables or data points using these methods does not fully explore the relationships underlying the outcome. More than one variable may be interacting with another to yield the observed outcome and as such pairwise testing would not represent this adequately. Thus, this piece of research employs multivariate statistics to fully represent any associations between variables and cases.

Graphical representation of categorical data

These techniques are a starting point for further examination of patterns. Using these begins data analysis of useful variables and patterns in the data which can then be investigated more closely. For example, if the statistical analysis yields interesting associations between certain variables, such as body regions, these approaches can yield information that can help identify patterns and determine further directions for study, such as indicators of blast injury for use in probabilistic modelling.

The chosen analyses (cluster analysis and multiple correspondence analysis) belong to the group termed geometric data analysis. These are multivariate techniques which represent clouds of points in dimensional space and use binary outcome variables. Using cluster analysis, the researcher can identify subgroups within and between samples to aid in the building of patterns of injury to describe the trauma sustained by the human skeleton following blast. Multiple correspondence analysis can be used to determine the principal components of the data that will reflect the best summary (Guinot et al. 2001). This allows showing associations between the cases as well as between the variables in a graphic summary (typically on two or three axes). The variables selected for each of these axes, or dimensions, are those which account for the most variance in the samples (Le Roux and Rouanet 2010).

This type of graphical summary makes it simpler to visualise relationships between cases and variables. Patterns of similar cases are represented by clouds of closely related points to illustrate the strength of the relationship. However, these methods are not without certain drawbacks. One important caveat to note is the subjectivity of this method. The patterns observed rely on the researcher's interpretation of these. To further ensure the suitability of the techniques in anthropological research these should be combined with other statistical methods such as those capable of measuring the strength of associations numerically. Combining both multivariate graphical statistics with the more commonly employed methods contributes a new approach to trauma studies in anthropology.

5.4.4. Predicting probability of cause of death - Binary logistic regression

To further the application of the relationships found in the graphical representations of the data, binary logistic regression is employed to develop a model which uses statistical probabilities to determine which group a case belongs to, in this case classifying injury patterns as being from gunshot trauma or blast injury.

This statistical methodology is related to linear and multiple regression, employing algebraic equations to predict category a specific case belongs to. In the case of binary logistic regression, the dependent and predictor variables are categorical with binary outcomes, necessitating a method which is based on transforming the data logarithmically to overcome the assumption of a linear relationship in basic regression (Field 2009). It permits the calculation of the probability of belonging to one outcome group or the other. This probability lays between 0 and 1, with 0 representing that the outcome is very unlikely to have occurred, and 1 the converse (Field 2009). Using binary logistic regression enables a statistical model to be developed which assesses the variables contributing to the prediction of the probability of the outcome. With this tool, it is possible to predict inclusion in a particular group of an unknown case (Hosmer and Stanley 2000; Peng et al. 2002; Peng and So 2002).

5.5. Methods

This section outlines the procedures followed when using SPSS 19.0 to analyse the data. This includes the exploratory phase, composed of basic frequencies, cluster analysis and multiple correspondence analysis, and followed by probability model building, using binary logistic regression.

5.5.1. Descriptives and Holm-Bonferroni corrected χ^2

The first step in the analysis is the calculation of frequencies. This was done in multiple phases to examine the data by cause of death (for the Bosnia sample) and by sample source (both the Bosnia and World War One samples). This was undertaken to permit calculation of prevalence in the samples to compare the Bosnia and World War One samples and the clinical literature.

Pearson's χ^2

Trauma analysis in anthropology frequently makes use of the χ^2 statistic to compare groups, specific characteristics between groups and within groups or variables. This is usually done simply, by comparing two variables using their frequencies (for example how many times a specific injury is found in one assemblage versus another) (Torres-Rouff and Costa Junqueira 2006; Owens 2007; Steyn et al. 2010; Erdal 2012). By using the Pearson's Chi-squared statistic, the researcher is testing the observed frequency of a variable against the expected frequency. This means that we measure the probability of seeing the same outcome in a variable by chance versus the one observed (such as in an assemblage or data set) (Field 2009).

The tests were carried out to look at multiple comparisons in the Bosnia data. Specifically, the researcher examined relationships between body region variables comparing the blast injury and gunshot wound cases.

Test statistics employed

Pearson's χ^2 was used unless certain assumptions were violated in the pairwise test. If the expected values were below five or were zero, a different test statistic was employed. In the case of expected value less than five, the Fisher's exact statistic is recommended. In cases of zero observations in a pairwise comparison, the Yates' continuity correction is recommended (Field 2009). All tests were done using Pearson's χ^2 unless otherwise stated.

Assumptions of the χ^2 test

For Pearson's Chi-Square test, there are two main assumptions. The first assumption is that the data must be independent. As such, a case cannot be represented twice in a contingency table. For the purposes of this research, there are no such cases. Secondly, expected frequencies should be larger than 5. This occurs in the sample but has been corrected for by employing the Fisher's Exact Test statistic in cases where this occurs.

Holm-Bonferroni correction

When performing multiple pairwise Chi-Square tests the possibility of a Type I error is increased. This causes the rejection of the null hypothesis (in this case, the null hypothesis is that there is no difference in the prevalence of trauma to the body region between blast injury and gunshot wound causes of death). As such, to accurately assess significance, a correction should be employed. This correction changes the typically used α-level (.05).

For the purposes of this research, the sequentially rejective version of the Bonferroni test is employed (Holm 1979), now commonly known as the Holm-Bonferroni correction. This methodology reduces the possibility of making a Type I error more than the Bonferroni method does, as it is less conservative than the traditional Bonferroni test (Holm 1979)

To accomplish this correction, the significance values of each pairwise test are compared from smallest to largest. This was accomplished by listing these in an excel table. Following this, the desired α is divided by the total number of pairwise tests. If the test statistic is found to be significant (at the adjusted α level), the null hypothesis is thus rejected. The significant value is then removed and the procedure is conducted once again, this time with the desired α level divided by the number of remaining pairwise tests. This is conducted sequentially (dividing α level by the number of pairwise tests) until the null hypothesis can no longer be rejected (Holm 1979).

This method of correction is used when pairwise Chi-Square tests are performed. It is applied to the significance level which corresponds to the selected test (i.e. Pearson Chi-Square, Fisher's Exact Test or Yates' Continuity Correction) based on the criteria explained in section 5.5.1.

5.5.2. **Cluster Analysis**

Cluster analysis is a classifying method of exploring data. It uses algebraic mathematical equations to compute distances between objects in multidimensional space (Burns and Burns 2013). In this research, each case and its corresponding outcome (absence or presence) for each of the variables (body regions affected/not affected by trauma) are analysed.

Cluster analysis is employed to reduce the data and create subgroups comprised of observed data, with the subgroups referred to as clusters (Řezanková and Everitt 2009; Burns and Burns 2013). The purpose of this method is to explore relationships between variables and cases to identify exemplars (for example patterns related to cause of death) as well as partitioning the sample in to homogeneous groups. These groups can form an “operational classification”. This method is advantageous when exploring a data set for which no prior theories have been formulated; such is the case in exploring a data set which has not been subjected to a breadth of statistical examination which goes beyond basic description. This methodology is the beginning of the process of identifying patterns within the data which can guide subsequent testing.

Conducting cluster analysis

The first step to conducting the cluster analysis is selecting the method which will be employed. Two typical methods are hierarchical or k-means cluster. In hierarchical clustering, the number of clusters needed is not known and is an exploratory method, whereas k-means clustering requires prior knowledge of the number of clusters (previously established groups in the data). The technique of hierarchical clustering was selected as this first step in the data analysis is exploratory and the current researcher wishes to identify any patterns in the data sets which can aid in the identification of combinations of trauma that indicate blast injury in the sample.

Hierarchical clustering begins with each case (or variable if the analysis is looking at relationships between variables) and employs an agglomerative process which combines cases (or variables) which are similar together to form a new cluster. This is the method employed for this research. Additionally, a specific measure is used to measure the similarity between cases/variables. The selected method was the binary squared Euclidean distance, a standard measure which relies on binary outcome variables, such as presence and absence. The binary squared Euclidean distance measure quantifies dissimilarity by measuring the distance between case in a cloud of points, representing similar objects as being close together in a group and those which are not as further apart. In calculating the distances between cases, it is the cases which are conflicting (such as absence of trauma in one cases compared to presence of trauma in another) which help the computer algorithm to determine that these cases are far apart in the Euclidean space. Therefore, cases with a disagreement are more important mathematically as these represent the maximum difference between the clusters. This clustering algorithm was chosen to examine where the differences in the patterns could be identified. Other methods were rejected as they are based on specific relationships between cases such as a probability that a characteristic present in one case predicts its presence in the compared case (IBM 2010). SPSS requires a method calculating distances between cases to be specified. The standard average linkage between groups was employed and measures the distance between each object in a proximity matrix. This is calculated as an extension of the Pythagorean Theorem which calculates the distances between objects in a multi-dimensional space. The average distance between members of a cluster is calculated and compared to those in another cluster rather than using single cases, such as the nearest or further case (as in single linkage or complete linkage methods).

The data were not standardized as the measurement level is the same for all the cases and variables (binary outcome). To assess the presence of patterns in the data, the blast injury and gunshot wound causes of death were employed in the first instance. The cluster analysis was employed to determine if there are any patterns that can be identified, such as clusters with particular types of injuries yielding a classification of trauma patterns in these assemblages. To ensure appropriate comparison of the two causes of death, it was necessary to subsample the gunshot wound group as this group was much larger than the blast injury group. This is accomplished using an automatic sampling syntax written specifically for this research. The syntax can be seen in Figure 5-2.

The first analysis looked at any patterns in the combined data set of the cases with blast injury and gunshot wound as the cause of death (with a subsample of the gunshot wound cases). Additionally, the blast injury and gunshot wound cases were examined individually. Again, the purpose of the cluster analysis here is to determine if there are any patterns and exemplars which can be used as indicators of a specific type of trauma, context or cause of death. Lastly, the variables were examined to determine if there was a pattern within the variables and if the variables differentiate between the cases in a sample encompassing all the graves. The results of these investigations will be used to formulate hypotheses and examine relationships between cases, causes of death, body region variables and within the individual graves which could lead to identification of indicators of blast injury assemblage patterns.

Binary cluster analysis syntax

To facilitate the examination of certain subsets of the data, such as the comparison of the blast trauma cases and the gunshot wound cases, it was necessary to create syntax to permit random subsampling from the cases with the cause of death listed as gunshot wound to create a better balanced sample of approximately 100 cases (this varied based on the automatic sampling of 11% of the gunshot wound cases), with 48 of those being from the smaller sample, the blast injury cases.

The following is an example of the code written, with the help of Dr. John Beavis of Bournemouth University. It was originally written to run an automatic subsampling routine for use in binary logistic regression and was adapted to perform cluster analysis. Figure 5-2: Cluster analysis syntax with random sampling represents the syntax for the cluster analysis performed to examine patterns in a combined data set with all the cases with blast injury and the randomly sampled gunshot wound cases. This was performed multiple times to determine the appropriate solution (with corresponding cluster numbers).

```
*GET FILE='\\bournemouth.ac.uk\data\Staff\Home\mcdussault\SPSS Data Analysis\cluster analysis\
Combined data set TEST.sav'.
SET RNG=MT MTINDEX=RANDOM.
DATASET NAME DataSet1 WINDOW=FRONT.
DATASET COPY  BI.
DATASET ACTIVATE  BI.
FILTER OFF.
USE ALL.
SELECT IF (COD=1).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET COPY  GSW.
DATASET ACTIVATE  GSW.
FILTER OFF.
USE ALL.
SELECT IF (COD=2).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET ACTIVATE GSW.
FILTER OFF.
USE ALL.
SAMPLE  .11.
EXECUTE.
DATASET ACTIVATE BI.
ADD FILES /FILE=*
 /FILE='GSW'.
EXECUTE.
CLUSTER NEUROCRANIUM to RFOOT
/MEASURE=BSEUCLID
/METHOD= DEFAULT
 /ID=Case#
  /PRINT SCHEDULE
  /PLOT DENDROGRAM
  /SAVE CLUSTER(6,7).
DATASET CLOSE GSW.
DATASET CLOSE BI.
DATASET ACTIVATE DataSet1.
```

Mersenne Twister random number generator for sub sampling command

Select data set for blast injury

Use all cases with C.O.D. = Blast

Select cases with C.O.D. = Gunshot Wound

Sample 11% of total, randomly using Mersenne Twister Random Number Generator

Add subsample to blast injury cases

Cluster selected variables

Binary Squared Euclidean Distance

Standard average linkage between groups

Label by Case# in output

Output tables and graphs

Figure 5-2: Cluster analysis syntax with random sampling

The syntax also includes sections at the bottom which produces the agglomeration schedule (/print command), the dendrogram and saves cluster membership for each included case into a table (/save command). A proximity matrix is also produced, which enables the exact distance between cases to be noted. This can demonstrate distances between specific cases within groups and between groups, aiding to mathematically represent the similarity and differences between the clusters.

Cluster membership for each case is listed in a table which identifies what cluster the case is part of, based on a range of solutions or a specific number of clusters pre-selected and input into the syntax. The agglomeration schedule aids in the determination of the optimal number of clusters in a solution (Table 5-5).

Table 5-5: Example agglomeration schedule.

Average Linkage (Between Groups)						
Agglomeration Schedule						
	Cluster Combined			Stage Cluster First Appears		
Stage	Cluster 1	Cluster 2	**Coefficients**	Cluster 1	Cluster 2	Next Stage
1	16	87	**.000**	0	0	13
2	36	86	**.000**	0	0	38
3	59	62	**.000**	0	0	4
4	53	59	**.000**	0	3	13
5	33	41	**.000**	0	0	14
6	2	9	**.000**	0	0	12
7	8	81	**1.000**	0	0	42
8	4	78	**1.000**	0	0	17
9	51	74	**1.000**	0	0	29
10	13	66	**1.000**	0	0	31
11	50	57	**1.000**	0	0	16
12	2	56	**1.000**	6	0	15
13	16	53	**1.000**	1	4	29
14	3	33	**1.000**	0	5	30
15	2	47	**1.333**	12	0	18
16	11	50	**1.500**	0	11	19
17	4	22	**1.500**	8	0	32
18	2	5	**1.500**	15	0	48
19	11	15	**1.667**	16	0	33
20	84	88	**2.000**	0	0	22
21	54	85	**2.000**	0	0	49
22	49	84	**2.000**	0	20	50
23	65	70	**2.000**	0	0	40
24	61	69	**2.000**	0	0	37
25	35	46	**2.000**	0	0	42

26	38	44	**2.000**	0	0	61
27	19	27	**2.000**	0	0	49
28	25	26	**2.000**	0	0	43
29	16	51	**2.100**	13	9	39
30	3	67	**2.333**	14	0	39
31	13	40	**2.500**	10	0	52
32	4	42	**2.667**	17	0	50
33	11	55	**2.750**	19	0	53
34	52	79	**3.000**	0	0	67
35	10	77	**3.000**	0	0	41
36	1	68	**3.000**	0	0	40
37	58	61	**3.000**	0	24	48
38	31	36	**3.000**	0	2	65
39	3	16	**3.250**	30	29	64
40	1	65	**3.500**	36	23	58
41	10	45	**3.500**	35	0	57
42	8	35	**3.500**	7	25	56
43	25	83	**4.000**	28	0	57
44	72	76	**4.000**	0	0	77
45	32	64	**4.000**	0	0	65
46	39	63	**4.000**	0	0	72
47	34	60	**4.000**	0	0	54
48	2	58	**4.000**	18	37	54
49	19	54	**4.000**	27	21	55
50	4	49	**4.000**	32	22	61
51	30	48	**4.000**	0	0	70
52	13	23	**4.000**	31	0	55
53	11	17	**4.000**	33	0	56
54	2	34	**4.375**	48	47	64
55	13	19	**4.500**	52	49	73
56	8	11	**4.500**	42	53	59
57	10	25	**4.556**	41	43	68
58	1	71	**4.750**	40	0	59
59	1	8	**4.900**	58	56	66
60	18	43	**5.000**	0	0	69
61	4	38	**5.000**	50	26	67
62	21	28	**5.000**	0	0	84
63	7	24	**5.000**	0	0	81
64	2	3	**5.182**	54	39	75
65	31	32	**5.333**	38	45	69
66	1	37	**5.467**	59	0	74
67	4	52	**5.611**	61	34	74
68	10	75	**5.833**	57	0	78
69	18	31	**5.900**	60	65	80
70	30	82	**6.000**	51	0	71
71	30	80	**6.000**	70	0	79
72	14	39	**6.000**	0	46	78
73	13	29	**6.000**	55	0	75
74	1	4	**6.000**	66	67	76
75	2	13	**6.418**	64	73	80
76	1	73	**6.926**	74	0	79
77	20	72	**7.000**	0	44	85
78	10	14	**7.143**	68	72	82
79	1	30	**7.196**	76	71	82
80	2	18	**7.214**	75	69	83
81	7	12	**7.500**	63	0	84
82	1	10	**7.600**	79	78	83
83	1	2	**8.253**	82	80	85
84	7	21	**8.833**	81	62	86
85	1	20	**8.835**	83	77	86
86	1	7	**9.702**	85	84	87

87	1	6	**10.655**	86	0	0

The agglomeration schedule is read from the bottom when using hierarchical agglomerative cluster analysis. The last line of the table represents a cluster solution with 1 cluster, all cases together. The most important line is the coefficient, representing the distance between the clusters (column in bold). A smaller coefficient in this type of analysis represents clusters which are close together or homogeneous. To determine where the optimal cut-off point to determine the number of clusters, the distance between the coefficients must be calculated. Where there is a large jump between the coefficients, this indicates a larger distance between the clusters and is a natural cut off point. The number of clusters is the number of the row with the lowest coefficient (not the stage number). As the table is read from the bottom up, the bottom row is a 1 cluster solution, the second to last row is a 2 cluster solution, and so forth (Nargundkar 2003).

The optimal solution determined by the coefficients between clusters can also be confirmed visually, using the dendrogram produced by SPSS.

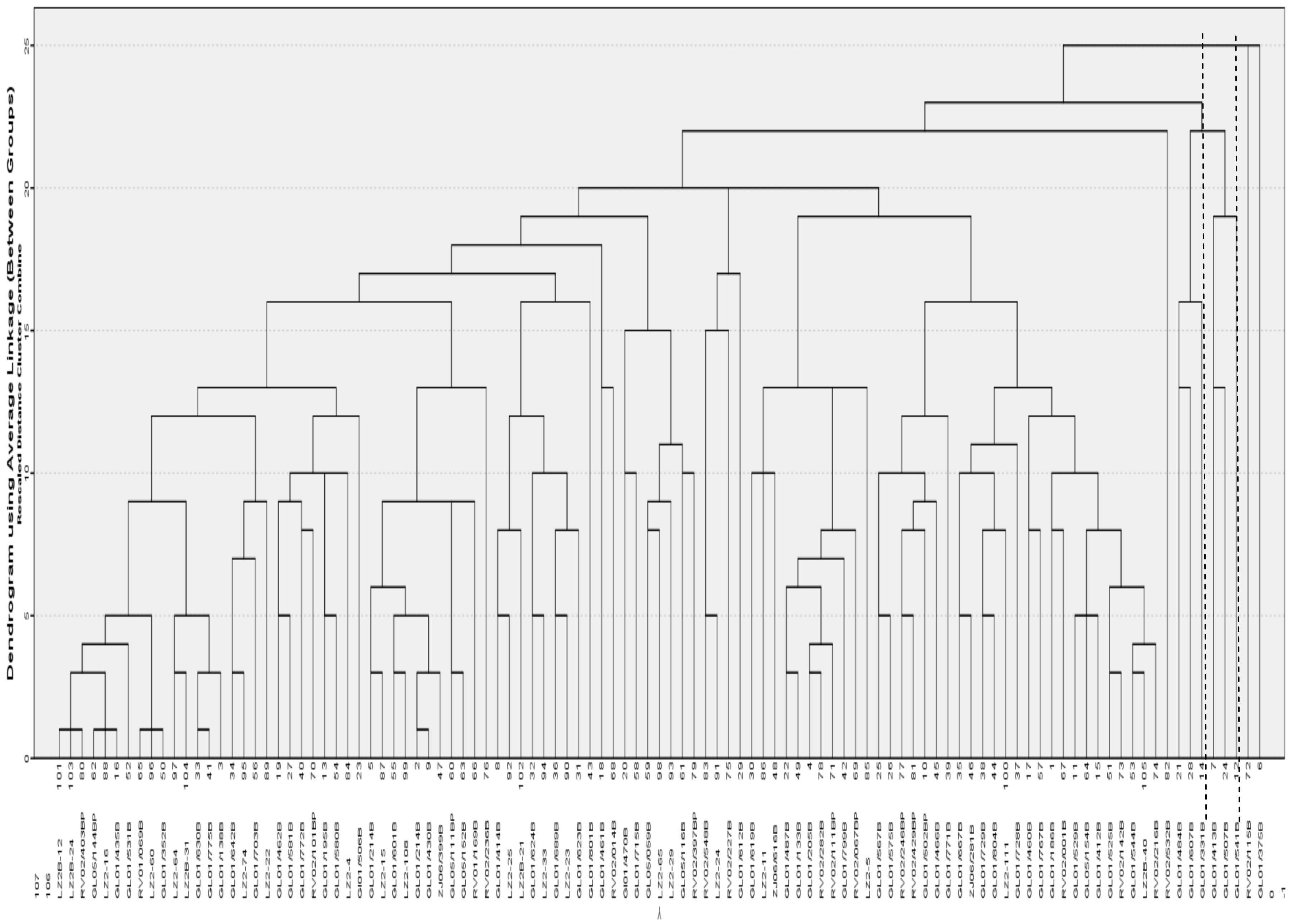

Figure 5-3: Dendrogram example

The dendrogram represents the associations between the cases (or variables if these are chosen). The diagram is read from left to right and the distance between two sequential vertical lines represents the re-scaled distances between the clusters. When there is a large distance between the two (with the ratio being the same as that of the coefficient differences from the agglomeration table), this indicates the mathematical break (based on coefficients) in the formation of clusters (Nargundkar 2003). Clusters to left of this point represent the clusters formed in the solution and the case numbers are listed to the left. To ease interpretation, a dendrogram in which patterns are identified and found to be useful in the interpretation of trauma patterns will have the break point illustrated and the clusters identified graphically.

5.5.3. **Multiple Correspondence Analysis**

The third step of the analysis is to perform a multiple correspondence analysis, to continue the exploration of the data. This examines the relationship between the two data sets and the contribution the variables make to the patterns in the data. By using this approach, variables which contribute to the patterns seen in the data can be identified and used in the subsequent binary logistic regression, as predictors of the cause of death variable. In the philosophy of inductive reasoning, this process permits geometric modelling techniques to lead to probabilistic models (Greenacre 1984).

Theory of multiple correspondence analysis

Multiple correspondence analysis belongs to the field of geometric data analysis, along with correspondence and principal components analysis. This type of analysis is based on linear algebra theory and is a geometric form of optimal scaling (Greenacre 1984; Le Roux and Rouanet 2010). It's popularity is most attributed to Jean-Paul Benzécri (Greenacre 1984). This technique looks at associations between elements of two sets and therefore can be used to explore the data from the blast injury cases and those with gunshot wounds. Two main types of correspondence analysis exist: using a cloud of categories or a cloud of individuals (Le Roux and Rouanet 2010). Multiple correspondence analysis is an extension of correspondence analysis. Rather than using 2 x 2 contingency tables (as in correspondence analysis), multiple correspondence analysis uses larger contingency tables and is applied with categorical variables (Le Roux and Rouanet 2010).

Multiple correspondence analysis with binary variables is considered a special case of this technique. It is closely related to principal components analysis of a matrix built from responses or outcomes. These are all standardized to have the same unit (if needed). Each discrete variable is represented by just one of its categories (i.e. Yes or no, present or absent) (Greenacre 1984). Like principal components analysis, multiple correspondence aids in the identification of the variables which contribute the most to the variance of the data. By identifying the variables, these can subsequently employed in further statistical analyses such as binary logistic regression (Le Roux and Rouanet 2010).

Multiple correspondence analysis methodology

The technique is based upon vector geometry, whereby each case is a vector (along a row of variables) and these can be represented in space (cloud of points or cloud of variables) (Greenacre 1984). The number of dimensions is represented by the number of variables minus one. Correspondence analysis helps to reduce the number of dimensions to represent the data graphically. Typically, this is done by using Euclidean space (Greenacre 1984). There are a variety of methods to represent the space, using formulas based on the Pythagorean Theorem. For this research, the Binary Squared Euclidean method is employed, typically an analysis method used for binary data. This will be explained further in this chapter.

The application of multiple correspondence analysis with SPSS is used to display the division of objects using categories (in this case the cause of death variable), thus representing graphically the relationships between the variables (Meulman et al. 2010). In multiple correspondence analysis, three assumptions need to be satisfied. The data must be at the multiple nominal scale and must contain at least 3 cases. The data used in this research satisfy both these conditions. The third is that the data must be coded as positive integers, again a condition with is met by the research, by coding the absent and present variables as 1 and 2. This methodology uses string variables which have been coded into positive integers.

For the purposes of this research, the analysis is conducted using the cases with blast injury or gunshot wound as the primary cause of death. This will permit exploration of the body region variables to discover which contribute most to the variance in the patterns between these two data sets. This will help to identify differences in the presentation of trauma in these two causes of death. Subsequently, these results can be applied to confirm the logistic regression model created in the following section of this chapter.

To counter the disparity in the size of both samples, the gunshot wound data is subsampled. This was repeated to assess which variables were found to consistently represent the largest variance in the samples on three dimensions (representing the data on three dimensions simplifies the visualisation to permit identification of the variables). Typically, most variance is accounted for on the first three dimensions (Le Roux and Rouanet 2010).

Multiple correspondence analysis using SPSS 19 requires the selection of a normalization method, which either optimises to look at associations between variables, individuals or symmetrically assess both. For the purposes of this research, the goal was to identify which body region variables differentiate between the two causes of death and as such the variable principal method was employed (Meulman et al. 2010). This will demonstrate the correlations between the variable and cause of death as well as how these contribute to the variance within and between the samples, identifying predictors of the dependent variable to use in probabilistic modelling (see 5.5.4 Binary logistic regression).

To determine which variables were important discriminating measures between the two samples, the discrimination measures were examined both visually and numerically across the dimensions selected. In the visual plot of the discrimination measures, those which are represented by points furthest from the origin are considered to discriminate most. Both the steepness and length of the line are observed to make this determination from the plot. Additionally, these are also noted numerically in the discrimination measures table in the SPSS output, noting the loading of each variable on the dimensions. The discrimination measures which were visually furthest from the origin on any dimension were selected as those which contribute the most variance to the samples.

To automate the process of random subsampling and apply the same procedures each time a subsample was created, syntax was written in the same manner as was written for the cluster analysis procedure; however, with different commands for the multiple correspondence analysis, following the subsampling. The following section shows the syntax for the complete procedure.

Multiple correspondence analysis syntax

The following is the syntax employed to automate the subsampling and application of the multiple correspondence analysis. The /print and /plot commands will be explained below the figure.

```
*GET FILE='C:\Users\Owner\Desktop\Combined data set.sav'.
 SET RNG=MT MTINDEX=RANDOM.
DATASET NAME DataSet1 WINDOW=FRONT.
DATASET COPY  BI.
DATASET ACTIVATE  BI.
FILTER OFF.
USE ALL.
SELECT IF (COD=1).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET COPY  GSW.
DATASET ACTIVATE  GSW.
FILTER OFF.
USE ALL.
SELECT IF (COD=2).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET ACTIVATE GSW.
FILTER OFF.
USE ALL.
SAMPLE  .11.
EXECUTE.
DATASET ACTIVATE BI.
ADD FILES /FILE=*
  /FILE='GSW'.
EXECUTE.
MULTIPLE CORRESPONDENCE /VARIABLES= COD NEUROCRANIUM TO LHAND
LRIBS TO LFOOT
/ANALYSIS=NEUROCRANIUM TO LHAND LRIBS TO LFOOT
/DIMENSION=2
/NORMALIZATION=VPRINCIPAL
/PRINT=DESCRIP(NEUROCRANIUM TO LHAND LRIBS TO LFOOT) DISCRIM
QUANT(NEUROCRANIUM TO LHAND LRIBS TO LFOOT) CORR

/PLOT= DISCRIM JOINTCAT OBJECT(COD NEUROCRANIUM TO LHAND LRIBS TO
LFOOT) .
DATASET CLOSE GSW.
DATASET CLOSE BI.
DATASET ACTIVATE DataSet1.
```

Mersenne Twister random number generator for sub sampling command

Select data set for blast injury

Use all cases with C.O.D. = Blast

Select cases with C.O.D. = Gunshot

Sample 11% of total, randomly using Mersenne Twister Random Number

Add subsample to blast injury cases

Variables for analysis

Optimize variable associations

Statistics to print in output

Plots to print in output

Figure 5-4- Multiple Correspondence Analysis Syntax

The /Print subcommand in the syntax is used to specify additional output desired alongside the Model Summary Statistics and the history statistics for the last iteration. The syntax line "DESCRIP(NEUROCRANIUM TO LHAND LRIBS TO LFOOT)" requests descriptives (frequency, missing values and mode) for the variables in the parentheses.

The syntax "DISCRIM" requests "Discrimination measures per variable and per dimension" (IBM 2010,p.1300). Following this, "QUANT(NEUROCRANIUM TO LHAND LRIBS TO LFOOT)" requests "Category quantifications (centroid coordinates), mass, inertia of the
categories, contribution of the categories to the inertia of the dimensions, and contribution of the dimensions to the inertia of the categories" (IBM 2010):1300. This aids in the discrimination of which variables contribute the most to the dimensions and to the variance of the samples. Each of these statistics indicates algebraic values used to calculate the position of the variables within the cloud of variables and thus assess the distance between the variables in a graphical manner. "Corr" requests correlation tables for the transformed variables.

The /Plot subcommand requests the display of specific plots. In the syntax for the multiple correspondence analysis above, three types of plots are requested. The first is the "DISCRIM" plot, which produces a plot of the discrimination measures. This produces the graphical representation of the variables along two dimensions, enabling the identification of which carry the most of the variance in the data. "JOINTCAT" produces a joint plot of category points over the two dimensions. This represents the category points for both the absent and present outcomes of each body region variable. "OBJECT" produces a plot of the object points over the two dimensions using the variables specified in the parentheses (IBM 2010).

This syntax was run multiple times to create subsampling that would be random and approximate the population from which it came, that is the larger gunshot wound data sample. Additionally, applying this method permitted the verification that the variables which contributed most to the variance were the ones which consistently were represented in the graphical output. These body region variables were then used in the subsequent analysis described in 5.5.4 which explains the binary logistic regression procedure used to build a predictive model.

5.5.4. Binary logistic regression

The final phase of the data analysis was performing binary logistic regression; a special case of regression which involves a log transformation of categorical data and uses binary outcome variables.

Logistic regression theory

Logistic regression permits group membership prediction (Tabachnick and Fidell 2007). The technique permits to evaluate the probability of group membership based on a combination of variables, called predictor variables. It is often used in medicine for the prediction of the presence or absence of disease (Tabachnick and Fidell 2007).

The advantage of using logistic regression is its lack of assumptions unlike many other techniques such as discriminant or multiway frequency analyses. The predictors need not be “normally distributed, linearly related, or of equal variance within each group” (Tabachnick and Fidell 2007). The emphasis of this technique is on the probability of the outcome based on the predictors and can help determine, in this piece of research, the probability of a cause of death being blast injury versus gunshot wound for a case with an unknown or ambiguous cause of death. Whilst this is an exploration of the potential to predict the cause of death or at least identify blast injury versus gunshot wounds in the assemblage, applying this technique to other assemblages could be explored further in future.

The binary logistic regression statistical test is used to develop a model predicting the probability of a case belonging to the gunshot wound or blast injury group, based on the presence or absence of trauma in certain body regions. The model is built through an iterative process which begins with a fully saturated model including all variables (body regions) and continues with the removal of variables which have no impact on the fit of the model. The backwards removal of predictors is preferable to minimise suppressor effects. This occurs when a variable has an effect only when another is kept constant in the analysis (Field 2009). The regression model uses the two outcome states, presence or absence, to evaluate the probability of a case belonging to a certain group based on the outcome of the cases response for each variable. Predictor variables can also be selected prior to analysis as opposed to letting SPSS pick these (IBM 2010). This is usually applied in combination with other statistical analyses or previously formulated hypotheses. In this project, variables identified in the multiple correspondence phase of the work are used as indicators.

To assess the goodness-of-fit of the model for each iteration, many statistic values are examined. Specifically this includes the log-likelihood, which examines the observed versus predicted model. A large log-likelihood statistic indicates a poorly fitting model. Additionally, examination of statistics related to each variable (body region) included in the model is made. This includes assessing a commonly used statistic, the R statistic. In binary logistic regression, the R statistic represents partial correlation between the dependent variable and the predictors. The ideal statistic to use in this case would be the Hosmer and Lemeshow's R^2_L (Hosmer and Stanley 2000) which assesses how the fit of a model improves with the inclusion of a specific variable. This is represented by a value between 0 and 1, making analysis straightforward. As R^2_L approaches 1 the model predicts outcome perfectly.

One of the most important statistics to examine is the odds ratio, represented by Exp(B). This indicates the ratio of change in odds (of the outcome) when the predictor level is changed (Field 2009). In binary cases, this means changing the predictor from 0 (the baseline or control state) to 1. This can be interpreted by looking at its value which when it is bigger than one indicates that as the predictor increases, the odds of the outcome occurring increases as well. When the value of the Exp(B) statistic is below one this means the odds of the outcome occurring are decreasing with the increase in predictor and as such the predictor is not suited to be used in the model (Field 2009).

According to Dr. D.J. Beavis, accuracy for the model built is better when using groups of approximately 50 cases each (personal communication, 4 April 2012). As such, SPSS was employed to randomly select 50 cases each from those in the data. These cases were imported in a new file to compile the final SPSS generated model. This was accomplished using a syntax file which permitted random sampling and automation of the process to ensure efficiency and repeatability for each of the iterations.

Binary logistic regression syntax

The following is an example of the syntax used to create the binary logistic regression model. Multiple iterations were performed, removing variables to obtain a more statistically accurate model whilst testing if the variables identified during the multiple correspondence analysis phases build the most accurate model.

```
*GET FILE='\\bournemouth.ac.uk\data\staff\home\mcdussault\Profile\Desktop\SPSS Data Analysis\binary logistic regression\Repeating BLR\Combined data set.sav'.
SET RNG=MT MTINDEX=RANDOM.
DATASET NAME DataSet1 WINDOW=FRONT.
DATASET COPY  BI.
DATASET ACTIVATE  BI.
FILTER OFF.
USE ALL.
SELECT IF (COD=1).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET COPY  GSW.
DATASET ACTIVATE  GSW.
FILTER OFF.
USE ALL.
SELECT IF (COD=2).
EXECUTE.
DATASET ACTIVATE  DataSet1.
DATASET ACTIVATE GSW.
FILTER OFF.
USE ALL.
SAMPLE  .11.
EXECUTE.
DATASET ACTIVATE BI.
ADD FILES /FILE=*
  /FILE='GSW'.
EXECUTE.
LOGISTIC REGRESSION VARIABLES COD
  /METHOD=ENTER Neurocranium Mandible LShoulder RShoulder LUpArm LRibs RRibs LPelvis RPelvis RFemur LFemur Maxillofacial Vertebrae
  /CONTRAST (Neurocranium)=Indicator
  /CONTRAST (Maxillofacial)=Indicator
  /CONTRAST (Mandible)=Indicator
  /CONTRAST (Vertebrae)=Indicator
  /CONTRAST (LShoulder)=Indicator
  /CONTRAST (RShoulder)=Indicator
  /CONTRAST (LUpArm)=Indicator
  /CONTRAST (RUpArm)=Indicator
  /CONTRAST (LForearm)=Indicator
  /CONTRAST (RForearm)=Indicator
  /CONTRAST (LHand)=Indicator
  /CONTRAST (RHand)=Indicator
  /CONTRAST (LRibs)=Indicator
  /CONTRAST (RRibs)=Indicator
  /CONTRAST (LPelvis)=Indicator
  /CONTRAST (RPelvis)=Indicator
  /CONTRAST (LFemur)=Indicator
  /CONTRAST (RFemur)=Indicator
  /CONTRAST (LTibFib)=Indicator
  /CONTRAST (RTibFib)=Indicator
  /CONTRAST (LFoot)=Indicator
  /CONTRAST (RFoot)=Indicator
  /CASEWISE OUTLIER(2)
  /PRINT=GOODFIT CI(95) ITER
  /CRITERIA=PIN(0.05) POUT(0.10) ITERATE(20) CUT(0.5).
DATASET CLOSE GSW.
DATASET CLOSE BI.
DATASET ACTIVATE DataSet1.
```

Mersenne Twister random number generator for sub sampling command

Select data set for blast injury cases

Use all cases with C.O.D. = Blast injury

Select cases with C.O.D. = Gunshot Wound

Sample 11% of total, randomly using Mersenne Twister Random Number Generator

Add subsample to blast injury cases

Independent variable

Dependent variables input into model

Dependent variables

List of outliers (more than 2 SRESID)

Goodness-of-fit statistic, confidence interval, intermediate estimates at each iteration

Default statistical criteria

Figure 5-5- Binary Logistic Regression Syntax

Specifically, following the random sampling method (as in the cluster analysis and the multiple correspondence analysis) the dependent variable is defined, here the cause of death. The independent (indicator/predictor) variables are listed subsequently.

Statistical tests are listed next. The outliers which do not fit into the model are listed, identified when these lie more than twice outside the value of the standard residual. The Hosmer and Lemeshow Goodness-of-Fit statistic is also printed in the output along with the 95% confidence interval for the Exp(B) statistic. The intermediate parameter estimates are printed for each iteration of the model.

The final line specifying how to run the test is the /criteria line which indicates which criteria to use for inclusion or exclusion of a predictor variable in the model. Each of these is included using their defaults as the criteria and was used as this model is being built without any preconceived notions regarding the statistics and is being built as an initial exploration into the possibility of prediction of cause of death. PIN(0.05) is the probability of a score statistic and the larger the probability, the more likely the inclusion in the model (IBM 2010). The POUT(0.1) command is the probability of the Likelihood Ratio cut off point for inclusion in the model. Again, the larger the number, the more it is likely to be included in the model (IBM 2010).

The ITERATE(20) specifies a maximum of 20 iterations to build the model. Again this is a default which is specified by SPSS 19 to maximise model building whilst keeping resources to a minimum. Finally the CUT(0.5) command is used to determine when a case is included in a specific group “when the predicted event probability is greater than or equal to the cutoff value” (IBM 2010).

Multicollinearity

A strong correlation between two or more predictors in a regression is considered multicollinearity and can affect the accuracy of the regression estimates (Field 2009). It can also affect the R statistic, limiting its size as well masking the importance of individual predictors (Field 2009). To assess multicollinearity, tolerance and variance inflation factors (VIF) are calculated using linear regression and the collinearity diagnostics in SPSS.

Tolerance of less than 0.2 and VIF of five or ten and more indicates a multicollinearity issue.

Block enter versus backwards binary logistic regression

To test which methodology is best to employ for the creation of model, the classification percentage and goodness-of-fit statistic were compared between the two methods employed. This was accomplished using an independent *t* test.

5.5.5. World War One sample and Clinical literature comparison

To assess where similarities or differences were between the Bosnia sample and the clinical literature and World War One samples, pairwise χ^2 was undertaken. The prevalence data from the literature and World War One sample were tested against prevalence of aggregated body regions in the Bosnia sample. Results are presented in Sections 6.6 and 6.7.

5.6. Summary

This chapter has introduced the methods employed for this research and includes a review of the epistemological and methodological framework, the data employed and the methodology used to analyse the data.

Inductive reasoning is highlighted as the framework for the analysis of two sources of data. The data is taken from pathological reports, autopsy photographs and excavation information from five graves in Bosnia, related to various events which occurred during the war in the Balkans. Data from World War One Canadian records of death is also described as a comparator to the results from the statistical analyses of the Bosnia data.

Preparation and coding of the data was undertaken, permitting a variety of statistical techniques to be employed. The methodology employed used an approach which began with the basic descriptive statistics commonly employed in anthropology and also the comparison of variables using Pearson's Chi-Square. Subsequently, multivariate methods were described, to explore geometric data analysis and its use in formulating hypotheses regarding the associations in the data, particularly looking at patterns which can help to identify cause of death in the large scale assemblages in Bosnia. Cluster analysis and multiple correspondence analysis were used in the first instance as these permit the exploration of the data and can contribute conclusions which can then, in the philosophy of inductive reasoning, move towards probabilistic modelling. To undertake the probabilistic modelling phase of the research, binary logistic regression was employed. All these techniques required the writing of syntax to specifically address subsampling of the data to permit the most accurate use of the statistical methodologies presented.

The following chapter describes the results of each of these analyses.

6. Results

This chapter presents the results of statistical analyses explained in the methods chapter. First, descriptives regarding the data sets are presented, presenting the frequencies related to the body region variables and the causes of death in both the Bosnia samples and the World War One sample.

Subsequently, Pearson's χ^2 tests with Holm-Bonferroni correction are presented to examine any relationships between the cause of death and the body region affected by trauma using pairwise comparisons. Additionally, the prevalence of trauma to the different body regions was compared between the five sites to determine if there was a difference in the prevalence of trauma to the body regions depending on the burial site. These results will be used to assess if the later multivariate methods employed detect relationships which are not seen in χ^2 testing as this is completed using pairwise contingency tables.

The results of the cluster analysis follows and highlights graphically any relationships within the samples. Clustering of individuals (by burial sites, cause of death, etc.) and by variable is presented. Multiple correspondence analysis completes the geometric representations of the data. Binary logistic regression is the last test presented in this chapter and outlines the probabilistic model built using an iterative process and the results of the multiple correspondence analysis.

6.1. Descriptives

This section presents the frequencies for each variable, cause of death and burial sites.

6.1.1. Bosnia

This section presents the frequency data for the Bosnia sample. It is divided according to burial sites, cause of death or has been combined to give an overall view of the sample.

Trauma divided by gravesites

Figure 6-1 and Table 6-1 present the frequencies of trauma to each body region, divided by each grave site.

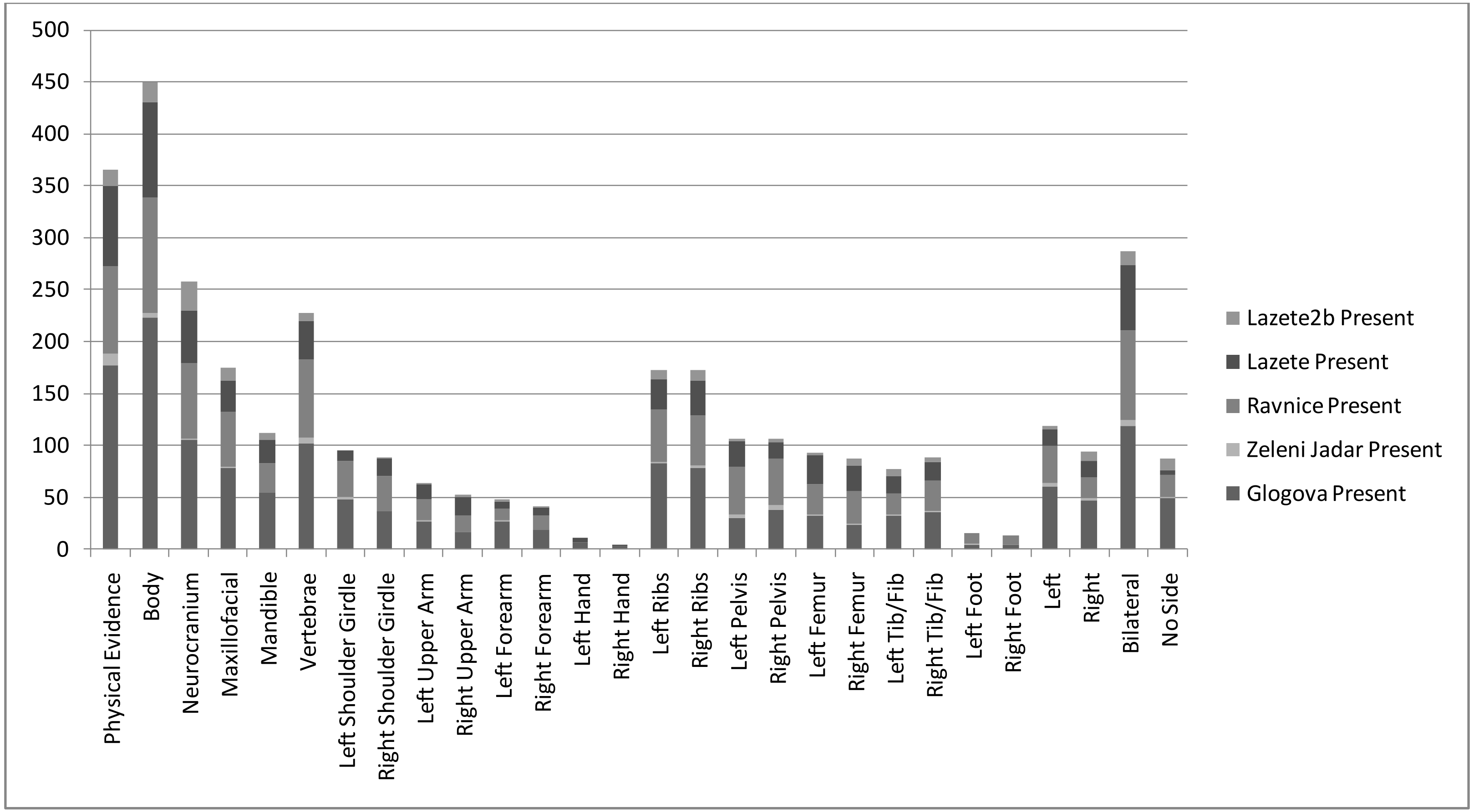

Figure 6-1: Trauma frequency by site. Each variable is represented with a stacked bar divided by the five sites.

Table 6-1: Frequency of trauma for each body region divided by site

Variable/Site	Glogova	Zeleni Jadar	Ravnice	Lazete	Lazete2b
Physical Evidence	177	11	84	78	16
Body	223	5	111	91	20
Neurocranium	105	1	73	51	28
Maxillofacial	79	1	52	30	13
Mandible	55	0	28	22	7
Vertebrae	102	6	75	37	8
Left Shoulder Girdle	48	2	35	10	0
Right Shoulder Girdle	37	0	34	17	1
Left Upper Arm	27	1	20	15	1
Right Upper Arm	17	0	15	19	2
Left Forearm	27	1	11	7	2
Right Forearm	19	0	13	8	2
Left Hand	7	0	0	4	0
Right Hand	3	1	0	1	0
Left Ribs	83	1	51	29	9
Right Ribs	79	2	48	34	10
Left Pelvis	30	4	46	24	3
Right Pelvis	38	5	44	16	4
Left Femur	32	2	29	28	2
Right Femur	24	1	31	25	6
Left Tib/Fib	33	1	20	17	6
Right Tib/Fib	36	1	29	18	5
Left Foot	5	1	10	0	0
Right Foot	5	0	9	0	0
Left	61	3	36	15	4
Right	47	2	21	15	9
Bilateral	119	5	87	63	13
No Side	49	2	21	4	11

Trauma in gunshot wound and blast injury cases

Figure 6-2 and Table 6-2 shows the frequency of gunshot wounds and blast injury divided by body regions.

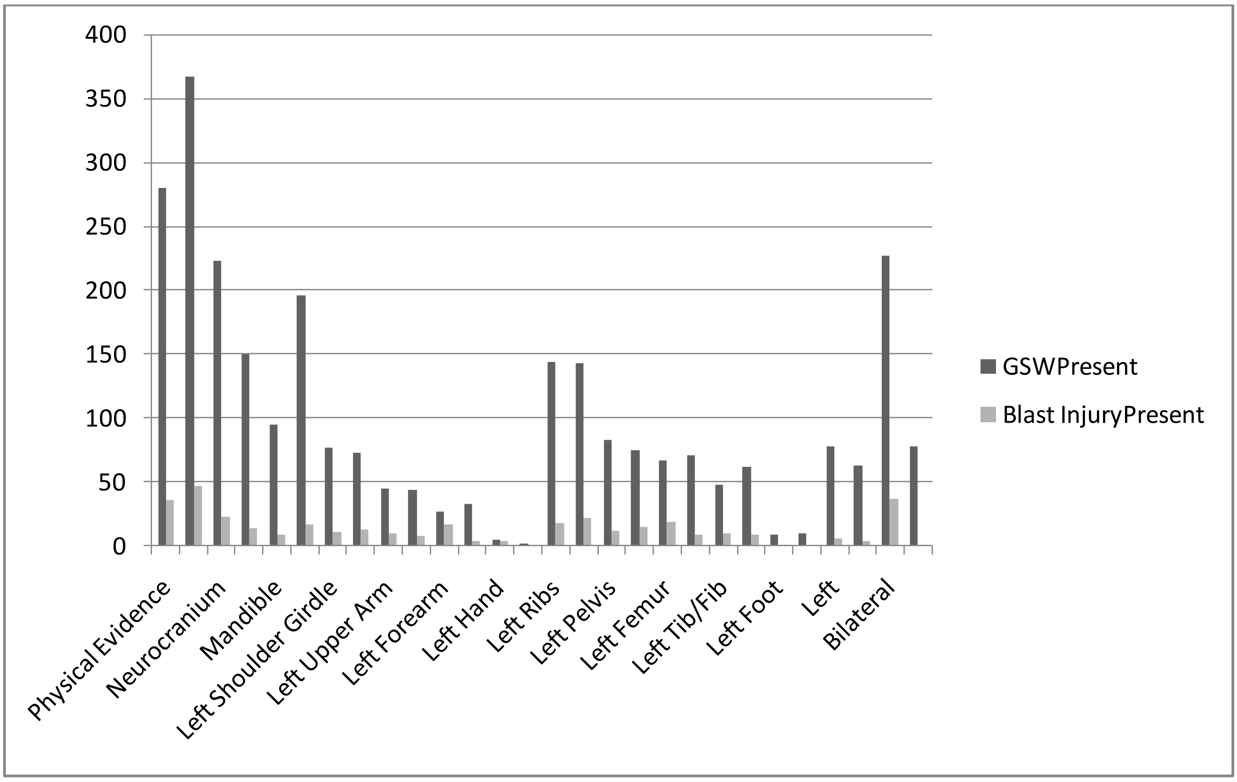

Figure 6-2: Presence of trauma to each body region for gunshot wound and blast injury cases.

Table 6-2: Frequency of trauma to each body region divided by cause of death

Variable/COD	GSW	Blast Injury
Physical Evidence	280	36
Body	367	47
Neurocranium	223	23
Maxillofacial	150	14
Mandible	95	9
Vertebrae	196	17
Left Shoulder Girdle	77	11
Right Shoulder Girdle	73	13
Left Upper Arm	45	10
Right Upper Arm	44	8
Left Forearm	27	17
Right Forearm	33	4
Left Hand	5	4
Right Hand	2	0
Left Ribs	144	18
Right Ribs	143	22
Left Pelvis	83	12
Right Pelvis	75	15
Left Femur	67	19
Right Femur	71	9
Left Tib/Fib	48	10
Right Tib/Fib	62	9
Left Foot	9	1
Right Foot	10	0
Left	78	6
Right	63	4
Bilateral	227	37
No Side	78	1

6.1.2. World War One

The following are the frequencies for the World War One sample.

Trauma divided by cause of death

In Figure 6-3 and Table 6-4, the presence of trauma is divided by the cause of death for each body region, either blast injury (BI) or gunshot wounds (GSW).

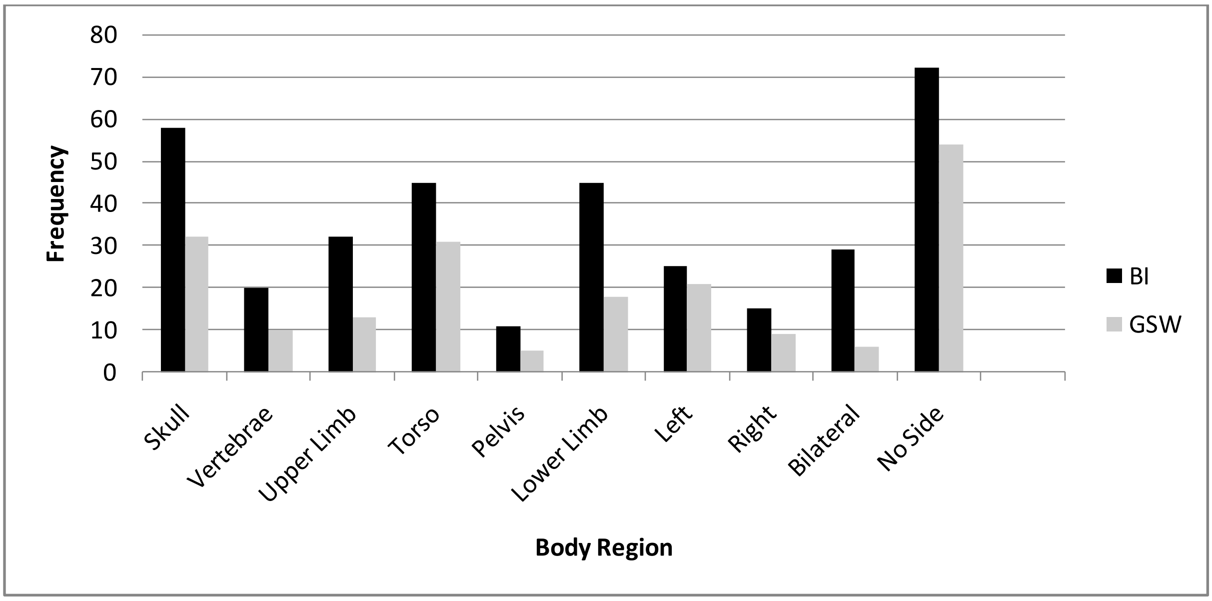

Figure 6-3: Frequency of the presence of trauma to each body region divided by cause of death.

Table 6-3: Frequency of trauma to each body region divided by cause of death

Variable/Cause of Death	**BI**	**GSW**
Skull	58	32
Vertebrae	20	10
Upper Limb	32	13
Torso	45	31
Pelvis	11	5
Lower Limb	45	18
Left	25	21
Right	15	9
Bilateral	29	6
No Side	72	54

6.2. Pearson's χ^2 – Comparing presence of trauma between blast injury and gunshot wound cause of death

Pearson's χ^2 tests were performed to answer specific questions within the Bosnia data. As the differentiation of blast trauma from other trauma is an objective of this research, Pearson's χ^2 were undertaken to compare the prevalence of injury to each body region between the blast injury and gunshot wound causes of death.

Neurocranium

Table 6-4 demonstrates expected and actual counts of trauma in the neurocranium for each cause of death. Although there were more cases of gunshot wounds deaths with neurocranium trauma, there was no significant association between neurocranium trauma and the cause of death in the sample $\chi^2(1, N= 491) = 0.102$, p=0.764.

Table 6-4: Contingency table for neurocranium variable comparing blast injury and gunshot wound cases.

			COD		Total
			BI	GSW	
Variable	Neurocranium Absent	Count	25	220	245
		Expected Count	24.0	221.0	245.0
		% within Variable	10.2%	89.8%	100.0%
		% within COD	52.1%	49.7%	49.9%
		% of Total	5.1%	44.8%	49.9%
		Std. Residual	.2	-.1	
	Neurocranium Present	Count	23	223	246
		Expected Count	24.0	222.0	246.0
		% within Variable	9.3%	90.7%	100.0%
		% within COD	47.9%	50.3%	50.1%
		% of Total	4.7%	45.4%	50.1%
		Std. Residual	-.2	.1	
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Maxillofacial trauma

Table 6-5 shows count and expected count of presence and absence of trauma to the maxillofacial body region. No significant association was found between maxillofacial trauma and cause of death, despite a higher proportion of gunshot wound cases having maxillofacial trauma $\chi^2(1, N= 491) = 0.429$, p=0.527.

Table 6-5: Contingency table for maxillofacial trauma variable comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Maxillofacial Absent	Count	34	293	327
		Expected Count	32.0	295.0	327.0
		% within Variable	10.4%	89.6%	100.0%
		% within COD	70.8%	66.1%	66.6%
		% of Total	6.9%	59.7%	66.6%
		Std. Residual	.4	-.1	
	Maxillofacial Present	Count	14	150	164
		Expected Count	16.0	148.0	164.0
		% within Variable	8.5%	91.5%	100.0%
		% within COD	29.2%	33.9%	33.4%
		% of Total	2.9%	30.5%	33.4%
		Std. Residual	-.5	.2	
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Mandibular trauma

Table 6-6 show the observed and expected counts of trauma to the mandible body region. Mandibular trauma was compared between blast injury and gunshot wound causes of death and no significant association was found $\chi^2(1, N= 491) =0.188$, p=0.716. Mandibular trauma was more prevalent in gunshot wound deaths than blast injury deaths, but not significantly.

Table 6-6: Contingency table for mandibular trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Mandible Absent	Count	39	348	387
		Expected Count	37.8	349.2	387.0
		% within Variable	10.1%	89.9%	100.0%
		% within COD	81.3%	78.6%	78.8%
		% of Total	7.9%	70.9%	78.8%
		Std. Residual	.2	-.1	
	Mandible Present	Count	9	95	104
		Expected Count	10.2	93.8	104.0
		% within Variable	8.7%	91.3%	100.0%
		% within COD	18.8%	21.4%	21.2%
		% of Total	1.8%	19.3%	21.2%
		Std. Residual	-.4	.1	
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Vertebral trauma

Table 6-7 shows the observed and expected counts of trauma to the vertebral body region. Vertebral trauma was 8.8% more prevalent in gunshot wound deaths than in blast injury deaths, however this difference was not significant $\chi^2(1, N= 491) =1.374$, $p=0.284$.

Table 6-7: Contingency table for vertebral trauma variable comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Vertebrae Absent	Count	31	247	278
		Expected Count	27.2	250.8	278.0
		% within Variable	11.2%	88.8%	100.0%
		% within COD	64.6%	55.8%	56.6%
		% of Total	6.3%	50.3%	56.6%
		Std. Residual	.7	-.2	
	Vertebrae Present	Count	17	196	213
		Expected Count	20.8	192.2	213.0
		% within Variable	8.0%	92.0%	100.0%
		% within COD	35.4%	44.2%	43.4%
		% of Total	3.5%	39.9%	43.4%
		Std. Residual	-.8	.3	
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left shoulder girdle trauma

Table 6-8 shows the observed and expected counts for trauma to the left shoulder girdle. Left shoulder girdle trauma was 5.5% more prevalent in the blast injury cases than in those with gunshot wounds as a cause of death. The difference was not significant $\chi^2(1, N=491) = 0.902$, $p = 0.427$.

Table 6-8: Contingency table for left shoulder girdle trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Shoulder Girdle Absent	Count	37	366	403
		Expected Count	39.4	363.6	403.0
		% within Variable	9.2%	90.8%	100.0%
		% within COD	77.1%	82.6%	82.1%
		% of Total	7.5%	74.5%	82.1%
	Left Shoulder Girdle Present	Count	11	77	88
		Expected Count	8.6	79.4	88.0
		% within Variable	12.5%	87.5%	100.0%
		% within COD	22.9%	17.4%	17.9%
		% of Total	2.2%	15.7%	17.9%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right shoulder girdle trauma

Table 6-9 shows the observed and expected counts for trauma to the right shoulder girdle variable. Right shoulder girdle trauma was found more in the blast injury cases than in the gunshot wound cases. The difference in prevalence was 10.6%. Despite the large difference in prevalence, it was not significant, however close $\chi^2(1, N= 491) = 3.371$, $p= 0.073$.

Table 6-9: Contingency table for right shoulder girdle trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Right Shoulder Girdle Absent	Count	35	370	405
		Expected Count	39.6	365.4	405.0
		% within Variable	8.6%	91.4%	100.0%
		% within COD	72.9%	83.5%	82.5%
		% of Total	7.1%	75.4%	82.5%
	Right Shoulder Girdle Present	Count	13	73	86
		Expected Count	8.4	77.6	86.0
		% within Variable	15.1%	84.9%	100.0%
		% within COD	27.1%	16.5%	17.5%
		% of Total	2.6%	14.9%	17.5%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left upper arm trauma

Table 6-10shows the observed and expected counts for left upper arm trauma. Left upper arm trauma was compared in the blast injury and gunshot wound cases and was found to be 10.6% more prevalent in the blast injury cases. The Pearson's Chi-Square test was found to be significant $\chi^2(1, N= 491) = 4.962$, $p= 0.032$. Applying the appropriate correction for multiple pairwise tests, the Holm-Bonferroni correction, reveals that this test is no longer significant as the test statistic *p*-value is larger than the corrected α-level.

Table 6-10: Contingency table for left upper arm trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Upper Arm Absent	Count	38	398	436
		Expected Count	42.6	393.4	436.0
		% within Variable	8.7%	91.3%	100.0%
		% within COD	79.2%	89.8%	88.8%
		% of Total	7.7%	81.1%	88.8%
	Left Upper Arm Present	Count	10	45	55
		Expected Count	5.4	49.6	55.0
		% within Variable	18.2%	81.8%	100.0%
		% within COD	20.8%	10.2%	11.2%
		% of Total	2.0%	9.2%	11.2%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right upper arm trauma

Table 6-11 shows the observed and expected counts of trauma for the right upper arm. Association between right upper arm trauma and cause of death was examined. Prevalence of right upper arm trauma in blast injury cases was 16.7% and 9.9% in gunshot wound deaths. This is a difference of 6.8%. Despite this difference in prevalence, it was found that right upper arm trauma was not significantly different between the two causes of death $\chi^2(1, N= 491) = 2.074$, $p= 0.212$.

Table 6-11: Contingency table for right upper arm trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Right Upper Arm Absent	Count	40	399	439
		Expected Count	42.9	396.1	439.0
		% within Variable	9.1%	90.9%	100.0%
		% within COD	83.3%	90.1%	89.4%
		% of Total	8.1%	81.3%	89.4%
	Right Upper Arm Present	Count	8	44	52
		Expected Count	5.1	46.9	52.0
		% within Variable	15.4%	84.6%	100.0%
		% within COD	16.7%	9.9%	10.6%
		% of Total	1.6%	9.0%	10.6%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left forearm trauma

Table 6-12 shows the observed and expected counts of trauma to the left forearm. Left forearm trauma prevalence between the blast injury cause of death and gunshot wound cause of death was quite different. 35.4% of the blast injury cases had left forearm trauma, compared with only 6.1% of cases in the gunshot wound death cohort. This large difference was found to be significant between the two, using Fisher's Exact test (due to an expected count lower than 5), $\chi^2(1, N= 491) = 45.640$, $p = 0.000$. Cramer's V was 0.305, indicating a medium effect size.

To appropriately evaluate the Chi-Square tests' significance, the α-level was corrected using the Holm-Bonferroni method and in this case the difference of left forearm trauma between blast injury and gunshot wound causes of death was found to be significant ($\alpha \leq 0.00227$).

Table 6-12: Contingency table for left forearm trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Forearm Absent	Count	31	416	447
		Expected Count	43.7	403.3	447.0
		% within Variable	6.9%	93.1%	100.0%
		% within COD	64.6%	93.9%	91.0%
		% of Total	6.3%	84.7%	91.0%
	Left Forearm Present	Count	17	27	44
		Expected Count	4.3	39.7	44.0
		% within Variable	38.6%	61.4%	100.0%
		% within COD	35.4%	6.1%	9.0%
		% of Total	3.5%	5.5%	9.0%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right forearm trauma

Table 6-13 shows the observed and expected counts of trauma for the right forearm variable. Right forearm trauma was slightly more prevalent in the blast injury group than in the gunshot wound group but the difference between the two was not significant, using Fisher's Exact Test (for a smaller than 5 expected count) $\chi^2(1, N= 491)$, $p = 0.774$.

Table 6-13: Contingency table for right forearm trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Right Forearm Absent	Count	44	410	454
		Expected Count	44.4	409.6	454.0
		% within Variable	9.7%	90.3%	100.0%
		% within COD	91.7%	92.6%	92.5%
		% of Total	9.0%	83.5%	92.5%
	Right Forearm Present	Count	4	33	37
		Expected Count	3.6	33.4	37.0
		% within Variable	10.8%	89.2%	100.0%
		% within COD	8.3%	7.4%	7.5%
		% of Total	.8%	6.7%	7.5%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left hand trauma

Table 6-14 shows the observed and expected counts for trauma to the left hand. Left hand trauma was found to be more prevalent in blast injury cases than in gunshot wound deaths, with a 7.2% difference between the two. This was found to be a significant difference between the two, using Fisher's Exact Test (with 1 cell having an expected count of 0.88), $\chi^2(1, N= 491)$, $p = 0.007$. Cramer's V value was 0.160 indicating a small effect size. Correcting for multiple pairwise tests using the Holm-Bonferroni method adjusted the α-level and this variable was shown to no longer be significant when comparing blast injury and gunshot wound-related causes of death.

Table 6-14: Contingency table for left hand trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Hand Absent	Count	44	438	482
		Expected Count	47.1	434.9	482.0
		% within Variable	9.1%	90.9%	100.0%
		% within COD	91.7%	98.9%	98.2%
		% of Total	9.0%	89.2%	98.2%
	Left Hand Present	Count	4	5	9
		Expected Count	.9	8.1	9.0
		% within Variable	44.4%	55.6%	100.0%
		% within COD	8.3%	1.1%	1.8%
		% of Total	.8%	1.0%	1.8%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right hand trauma

Table 6-15 represents the observed and expected counts for trauma to the right hand. Right hand trauma was not identified in any of the cases of blast injury and in only two of the gunshot wound related deaths. Fisher's Exact Test was employed due to 2 cells having expected counts lower than 5. Right hand trauma was not significant between the causes of death $\chi^2(1, N= 491)$, $p = 1.000$.

Table 6-15: Contingency table for right hand trauma comparing blast injury and gunshot wound cases.

			COD		Total
			BI	GSW	
Variable	Right Hand Absent	Count	48	441	489
		Expected Count	47.8	441.2	489.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	99.5%	99.6%
		% of Total	9.8%	89.8%	99.6%
	Right Hand Present	Count	0	2	2
		Expected Count	.2	1.8	2.0
		% within Variable	.0%	100.0%	100.0%
		% within COD	.0%	.5%	.4%
		% of Total	.0%	.4%	.4%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left rib trauma

Table 6-16 represents the observed and expected count of trauma to the left ribs. Left rib trauma was found in 18 cases in the blast injury cohort and 144 cases in the gunshot wound death cohort. There was a small difference of 5% between the two causes of death but this was not found to be significant $\chi^2(1, N= 491) = .489$, $p = 0.519$.

Table 6-16: Contingency table for left rib trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Ribs Absent	Count	30	299	329
		Expected Count	32.2	296.8	329.0
		% within Variable	9.1%	90.9%	100.0%
		% within COD	62.5%	67.5%	67.0%
		% of Total	6.1%	60.9%	67.0%
	Left Ribs Present	Count	18	144	162
		Expected Count	15.8	146.2	162.0
		% within Variable	11.1%	88.9%	100.0%
		% within COD	37.5%	32.5%	33.0%
		% of Total	3.7%	29.3%	33.0%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right rib trauma

Table 6-17 represents the observed and expected count of right rib trauma. Right rib trauma was found to be not significantly different between the two cohorts $\chi^2(1, N = 491) = 3.566$, $p = 0.076$ despite a rather large difference in the prevalence of this type of trauma (13.5%). Blast injury related deaths were affected by more right rib trauma than those killed by gunshot wounds.

Table 6-17: Contingency table for right rib trauma comparing blast injury and gunshot wound cases.

			COD		Total
			BI	GSW	
Variable	Right Ribs Absent	Count	26	300	326
		Expected Count	31.9	294.1	326.0
		% within Variable	8.0%	92.0%	100.0%
		% within COD	54.2%	67.7%	66.4%
		% of Total	5.3%	61.1%	66.4%
	Right Ribs Present	Count	22	143	165
		Expected Count	16.1	148.9	165.0
		% within Variable	13.3%	86.7%	100.0%
		% within COD	45.8%	32.3%	33.6%
		% of Total	4.5%	29.1%	33.6%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left pelvis trauma

Table 6-18 presents the observed and expected counts of trauma to the left pelvis again, a large difference in prevalence was found between the blast injury and gunshot wound causes of death, with a difference of 6.3%. However, using Pearson's Chi-Square no significant difference was found for this type of trauma and cause of death $\chi^2(1, N{=}\,491) = 1.089$, $p = 0.335$.

Table 6-18: Contingency table for left pelvis trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Pelvis Absent	Count	36	360	396
		Expected Count	38.7	357.3	396.0
		% within Variable	9.1%	90.9%	100.0%
		% within COD	75.0%	81.3%	80.7%
		% of Total	7.3%	73.3%	80.7%
	Left Pelvis Present	Count	12	83	95
		Expected Count	9.3	85.7	95.0
		% within Variable	12.6%	87.4%	100.0%
		% within COD	25.0%	18.7%	19.3%
		% of Total	2.4%	16.9%	19.3%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right pelvis trauma

Table 6-19 represents the observed and expected counts of trauma to the right pelvis. Conversely to the left pelvis, the presence of trauma to the right pelvis was found to be significantly different depending on the cause of death $\chi^2(1, N= 491) = 5.932$, $p = .019$. This is further seen when comparing the prevalence of right pelvic trauma in blast injury cases (31.3%) to that seen in gunshot wound cases (16.9%). This is a difference of 14.4%. The effect size is however small, as seen by the Cramer's V of 0.110. Applying the Holm-Bonferroni correction for multiple pairwise tests adjusted the cut-off significance value and it was found that at this new α-level, the presence of trauma to the right pelvis was no longer significant.

Table 6-19: Contingency table for right pelvis trauma comparing blast injury cases and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	RPelvis Absent	Count	33	368	401
		Expected Count	39.2	361.8	401.0
		% within Variable	8.2%	91.8%	100.0%
		% within COD	68.8%	83.1%	81.7%
		% of Total	6.7%	74.9%	81.7%
	RPelvis Present	Count	15	75	90
		Expected Count	8.8	81.2	90.0
		% within Variable	16.7%	83.3%	100.0%
		% within COD	31.3%	16.9%	18.3%
		% of Total	3.1%	15.3%	18.3%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left femur trauma

Table 6-20 represents the observed and expected counts of trauma to the left femur. Left femur trauma was found in 19 cases of blast injury deaths (39.6%) and in only 15.1% (N= 67) of the gunshot wound deaths, an evidently large difference of 24.5%. This represents a significant finding $\chi^2(1, N= 491) = 17.933$, $p = 0.000$. Using the Holm-Bonferroni correction for multiple pairwise tests, left femur trauma was still significant with $p \leq 0.00238$. The effect is considered small though, with the Cramer's V value being 0.191.

Table 6-20: Contingency table for left femur trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Femur Absent	Count	29	376	405
		Expected Count	39.6	365.4	405.0
		% within Variable	7.2%	92.8%	100.0%
		% within COD	60.4%	84.9%	82.5%
		% of Total	5.9%	76.6%	82.5%
	Left Femur Present	Count	19	67	86
		Expected Count	8.4	77.6	86.0
		% within Variable	22.1%	77.9%	100.0%
		% within COD	39.6%	15.1%	17.5%
		% of Total	3.9%	13.6%	17.5%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right femur trauma

Table 6-21 represents the observed and expected counts of trauma to the right femur. Right femoral trauma was noted on 9 cases in the blast injury group and 71 in the gunshot trauma group. This represents a small difference in the prevalence percentage between the two; with blast injury have 2.2% more cases of right femoral trauma. This was not a significant difference between the two causes of death $\chi^2(1, N= 491) = 0.235$, $p = 0.680$.

Table 6-21: Contingency table for right femur trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	RFemur Absent	Count	39	372	411
		Expected Count	40.2	370.8	411.0
		% within Variable	9.5%	90.5%	100.0%
		% within COD	81.3%	84.0%	83.7%
		% of Total	7.9%	75.8%	83.7%
	RFemur Present	Count	9	71	80
		Expected Count	7.8	72.2	80.0
		% within Variable	11.3%	88.8%	100.0%
		% within COD	18.8%	16.0%	16.3%
		% of Total	1.8%	14.5%	16.3%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left tibia and fibula trauma

Table 6-22 represents the observed and expected number of trauma to the left tibia and fibula. The trauma to the left tibia and fibula was markedly higher in the blast injury group, which had a prevalence of 20.8% (N= 10). The gunshot wound cases were found to have 10.8% of cases with left tibia and fibula trauma (N=48). Despite this difference of 10% in prevalence between the two, it was not significant, although very close to being $\chi^2(1, N= 491) = 4.156$, $p = 0.057$.

Table 6-22: Contingency table for left tibia and fibula trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	LTib/Fib Absent	Count	38	395	433
		Expected Count	42.3	390.7	433.0
		% within Variable	8.8%	91.2%	100.0%
		% within COD	79.2%	89.2%	88.2%
		% of Total	7.7%	80.4%	88.2%
	LTib/Fib Present	Count	10	48	58
		Expected Count	5.7	52.3	58.0
		% within Variable	17.2%	82.8%	100.0%
		% within COD	20.8%	10.8%	11.8%
		% of Total	2.0%	9.8%	11.8%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right tibia and fibula trauma

Table 6-23 represents the observed and expected number of trauma to the right tibia and fibula. The right tibia and fibula did not exhibit a large difference in prevalence. Blast injury cases had this type of trauma in 18.8% (N= 9) of cases and gunshot wound in 14.0% (N= 62) of cases. This does not represent a significant difference between the two causes of death $\chi^2(1, N= 491) = 0.791$, $p = 0.387$.

Table 6-23: Contingency table for right tibia and fibula trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	RTib/Fib Absent	Count	39	381	420
		Expected Count	41.1	378.9	420.0
		% within Variable	9.3%	90.7%	100.0%
		% within COD	81.3%	86.0%	85.5%
		% of Total	7.9%	77.6%	85.5%
	RTib/Fib Present	Count	9	62	71
		Expected Count	6.9	64.1	71.0
		% within Variable	12.7%	87.3%	100.0%
		% within COD	18.8%	14.0%	14.5%
		% of Total	1.8%	12.6%	14.5%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Left foot trauma

Table 6-24 represents the observed and expected number of trauma to the left foot. Left foot trauma was rare in both the cohorts studied, with one case in the blast injury group and nine in the gunshot wound group, with a 2.1% and 2% prevalence respectively. The comparison was not significant between the causes of death $\chi^2(1, N= 491)$, $p = 1.000$ (using Fisher's Exact Test due to an expected count below 5).

Table 6-24: Contingency table for left foot trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	LFoot Absent	Count	47	434	481
		Expected Count	47.0	434.0	481.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	97.9%	98.0%	98.0%
		% of Total	9.6%	88.4%	98.0%
	LFoot Present	Count	1	9	10
		Expected Count	1.0	9.0	10.0
		% within Variable	10.0%	90.0%	100.0%
		% within COD	2.1%	2.0%	2.0%
		% of Total	.2%	1.8%	2.0%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Right foot trauma

Table 6-25 represents the observed and expected counts of trauma to the right foot. Right foot trauma was different from left foot trauma. The right foot was found in no cases in the blast injury cohort and in 78 cases in the gunshot wound cohort. Due to a count of 0 in the blast injury cohort, the Yates' Continuity Correction was used as the Chi-Square test, which found a significant difference between the two causes of death for right foot trauma $\chi^2(1, N= 491) = 8.773$, $p = 0.003$. The effect size is small, with Cramer's V being 0.143.

Holm-Bonferroni correction for multiple pairwise tests was employed and at this point, it was determined that right foot trauma was not significantly different between the causes of death as the cut-off point was $p \leq 0.00238$.

Table 6-25: Contingency table for right foot trauma comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	RFoot Absent	Count	48	365	413
		Expected Count	40.4	372.6	413.0
		% within Variable	11.6%	88.4%	100.0%
		% within COD	100.0%	82.4%	84.1%
		% of Total	9.8%	74.3%	84.1%
	RFoot Present	Count	0	78	78
		Expected Count	7.6	70.4	78.0
		% within Variable	.0%	100.0%	100.0%
		% within COD	.0%	17.6%	15.9%
		% of Total	.0%	15.9%	15.9%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Trauma to the left side of the body

Table 6-26 represents the observed and expected counts of trauma to the left side of the body. Cases with trauma located solely to the left side of the body were compared between the blast injury and gunshot wound causes of death. In the former, 6 cases had trauma only to the left side and the latter had 78 cases. This represents a prevalence of 12.5% and 17.6% respectively. The difference is 5.1%, with gunshot wound cases having a higher prevalence. This difference was not found to be significant $\chi^2(1, N= 491) = 0.797$, p = 0.427.

Table 6-26: Contingency table for trauma to the left side of the body comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Left Absent	Count	42	365	407
		Expected Count	39.8	367.2	407.0
		% within Variable	10.3%	89.7%	100.0%
		% within COD	87.5%	82.4%	82.9%
		% of Total	8.6%	74.3%	82.9%
	Left Present	Count	6	78	84
		Expected Count	8.2	75.8	84.0
		% within Variable	7.1%	92.9%	100.0%
		% within COD	12.5%	17.6%	17.1%
		% of Total	1.2%	15.9%	17.1%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Trauma to the right side of the body

Table 6-27 represents the observed and expected counts of trauma to the right side of the body. The right side of the body showed trauma in four cases in the blast injury group and 63 cases in the gunshot wound group. These numbers represent a prevalence of 8.3% and 14.2%, with a difference of 5.9%. Again, the right side variable was not significant between the two causes of death $\chi^2(1, N = 491) = 1.274$, $p = 0.284$

Table 6-27: Contingency table for trauma to the right side of the body comparing blast injury and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Right Absent	Count	44	380	424
		Expected Count	41.5	382.5	424.0
		% within Variable	10.4%	89.6%	100.0%
		% within COD	91.7%	85.8%	86.4%
		% of Total	9.0%	77.4%	86.4%
	Right Present	Count	4	63	67
		Expected Count	6.5	60.5	67.0
		% within Variable	6.0%	94.0%	100.0%
		% within COD	8.3%	14.2%	13.6%
		% of Total	.8%	12.8%	13.6%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Bilateral trauma to the body

Table 6-28 represents the observed and expected counts of trauma bilaterally. Bilateral trauma to the body indicated injury that could be found on both sides of the body at the same time. In the blast injury group, 37 cases were affected on both sides and 227 in the gunshot wound group. This was a prevalence of 77.1% for the blast injury group and 51.2% for the gunshot wound group, a difference of 25.9% between the two. This represents a significant differences for the causes of death $\chi^2(1, N= 491) = 11.634$, $p = 0.001$. Following Holm-Bonferroni correction, the difference between the causes of death remained significant. The size of the effect is small, indicated by the value of Cramer's V (0.154).

Table 6-28: Contingency table for bilateral trauma variable comparing blast injury cases and gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	Bilateral Absent	Count	11	216	227
		Expected Count	22.2	204.8	227.0
		% within Variable	4.8%	95.2%	100.0%
		% within COD	22.9%	48.8%	46.2%
		% of Total	2.2%	44.0%	46.2%
	Bilateral Present	Count	37	227	264
		Expected Count	25.8	238.2	264.0
		% within Variable	14.0%	86.0%	100.0%
		% within COD	77.1%	51.2%	53.8%
		% of Total	7.5%	46.2%	53.8%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Unsided trauma to the body

Table 6-29 represents the observed and expected counts of trauma to the unsided regions of the body (such as vertebrae). Cases with trauma in unsided areas were found in both groups. In the blast injury group, there was one case with trauma to an unsided area only (which is either the spine or the head area solely). In the gunshot wound cases, there were 78 cases with unsided trauma. There was much more trauma in the gunshot wound cases, with 17.6% of the sample having this type of trauma versus 2.1% in the blast injury group (a difference of 15.5%). This difference was significant $\chi^2(1, N= 491) = 7.730$, $p = 0.006$. Using the Holm-Bonferroni correction for multiple pairwise tests, this variable remained significantly different between blast injury and gunshot wound cases. The effect size was small, Cramer's V value = 0.125.

Table 6-29: Contingency table for unsided trauma to the body comparing blast injury gunshot wound cases.

			COD		
			BI	GSW	Total
Variable	NoSide Absent	Count	47	365	412
		Expected Count	40.3	371.7	412.0
		% within Variable	11.4%	88.6%	100.0%
		% within COD	97.9%	82.4%	83.9%
		% of Total	9.6%	74.3%	83.9%
	NoSide Present	Count	1	78	79
		Expected Count	7.7	71.3	79.0
		% within Variable	1.3%	98.7%	100.0%
		% within COD	2.1%	17.6%	16.1%
		% of Total	.2%	15.9%	16.1%
Total		Count	48	443	491
		Expected Count	48.0	443.0	491.0
		% within Variable	9.8%	90.2%	100.0%
		% within COD	100.0%	100.0%	100.0%
		% of Total	9.8%	90.2%	100.0%

Body regions significantly different between blast injury and gunshot wound cases

Using the χ^2 test of significance has found that for the body region variables, once corrected using the Holm-Bonferroni correction, left forearm and left femur trauma were the only two which were significantly different between the blast injury cause of death and the gunshot wound cause of death, seen in Figure 6-4: Body regions of significant different between blast injury and gunshot wound cases in the Bosnia sample. In the side variables, both the bilateral and unsided trauma variables were significant, after Holm-Bonferroni correction. In the case of left forearm, left femur and bilateral trauma, the prevalence was significantly higher in the blast injury cases. In the gunshot wound cases, the presence of unsided trauma was significantly different to that in blast injury.

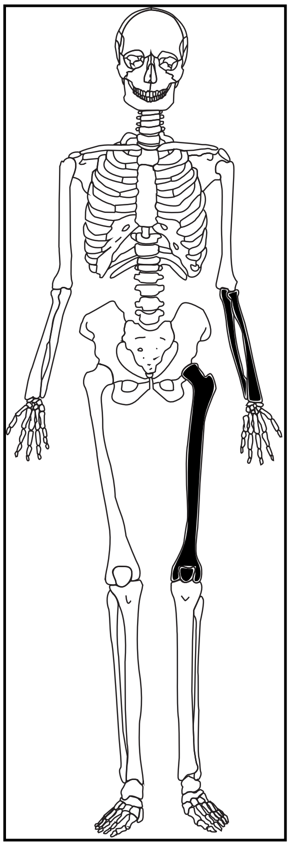

Figure 6-4: Body regions of significant different between blast injury and gunshot wound cases in the Bosnia sample

6.3. Cluster analysis

This section presents the results of the cluster analysis performed on the samples from Bosnia. This was performed using SPSS 19 and was repeated to examine various associations and patterns within the data. The clustering was performed within the causes of death individually, between the blast injury and gunshot wound causes of death and finally between the variables. The results of these analyses are presented below.

6.3.1. Clustering within causes of death

Blast injury

Clustering was performed on all cases with the cause of death listed as being blast injury in the pathology reports. A final 48 cases were selected for analysis. The analysis was performed using the binary squared Euclidean distance measure. The agglomeration schedule determined that the largest difference between coefficients was seen between the 1-cluster and 2-cluster solutions, a difference of 0.961. The subsequent clustering in the agglomeration schedule revealed no larger difference between steps, indicating that the ideal solution is a 2 cluster solution.

The dendrogram below illustrates visually the cluster analysis solution. Visually, one very large cluster and a small cluster of two cases can be seen for a two cluster solution. The natural breakpoint is seen in the very large distance between the left start point at case GL01/375B and the next consecutive vertical line, which is the largest distance between consecutive vertical lines. This separation is shown by the dashed line on the dendrogram in Figure 6-5. Using the cluster membership output, it is confirmed that for a two cluster solution, cases GL01/375B and GL01/541B belong to cluster number two, with all other cases being assigned to cluster 1.

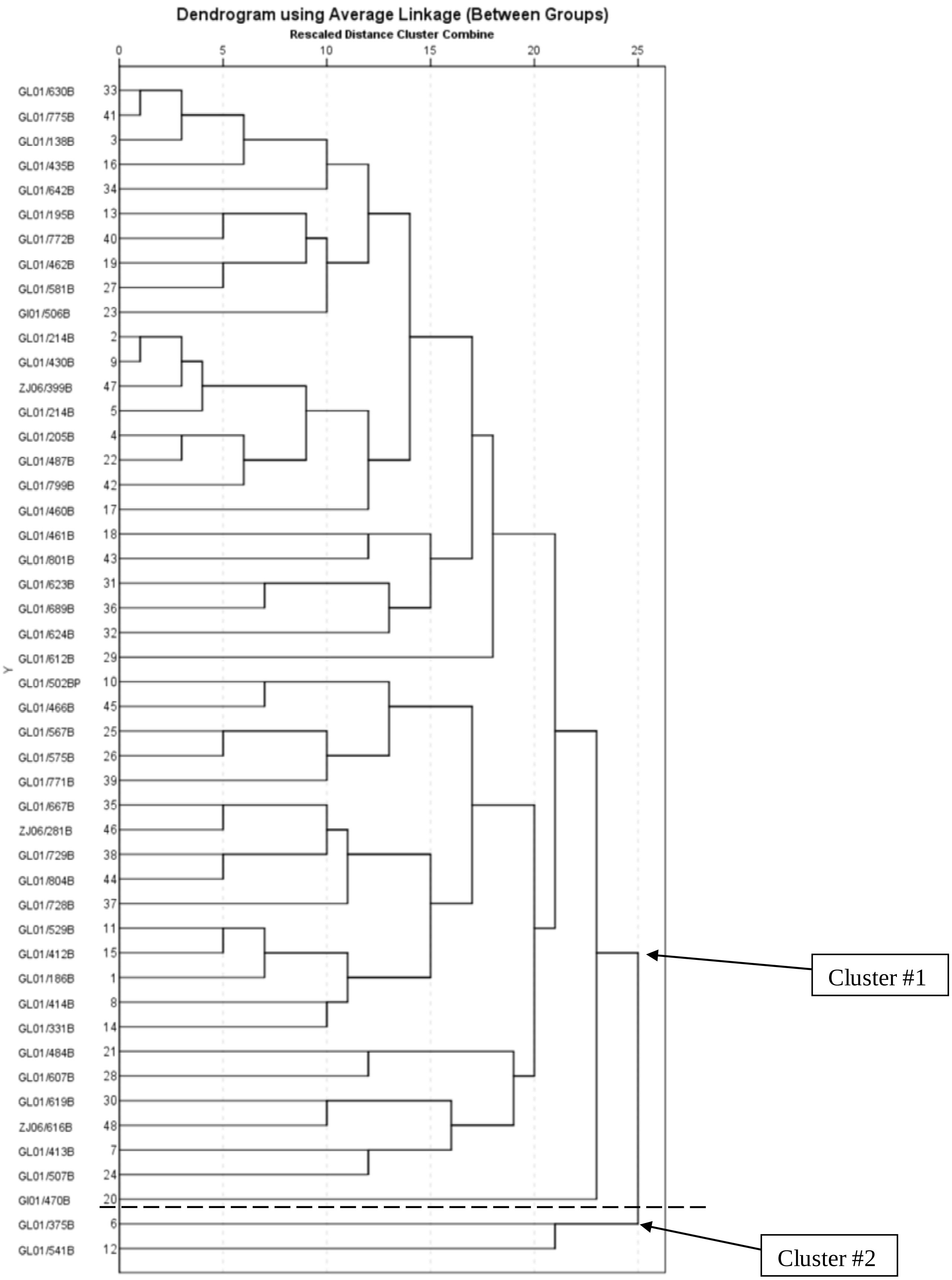

Figure 6-5: Cluster analysis of blast injury cases with 2 cluster solution demonstrated at the dashed line.

Gunshot wound

The gunshot wound group is composed of 443 cases whose cause of death is listed as being gunshot wound by the pathologist. The group was analysed next using binary squared Euclidean distance and complete linkage method. Examining the agglomeration schedule, the largest difference between two coefficients was calculated as being between the three and four cluster solutions (Appendix A). The coefficient for a three cluster solution is 10.200 and the four cluster solution is 9.000, a difference of 1.200. Therefore, the 4 cluster solution is chosen, based on the distance between the 3 and 4 cluster solutions being the largest, indicating a mathematical difference between the clusters .

Visually, the distinction between the four groups is difficult to ascertain, as seen in Figure 6-6. Throughout the agglomeration schedule, the differences between the steps in the cluster process are very small. Relying solely on a visual examination of the patterns in the dendrogram, 4 groups can be identified, however this is challenging due to the size of the dendrogram and the amount of cases.

The cluster membership output produced by SPSS identifies the cases which belong to each cluster, simplifying the task. Table 6-30 indicates cluster membership, for clusters 2, 3, and 4. Cluster 1 was composed of the remaining cases.

Table 6-30: Cluster membership in cluster analysis of gunshot wound cases. All other cases were clustered in the first cluster. All cases had gunshot wounds as the cause of death.

Case #	Cluster
RV02/126B	2
RV02/356B	2
RV02/532B	2
RV02/204B	3
RV02/237B	3
RV02/314B	3
RV02/573B	3
LZ2/17B	3
GL01/179B	4

Cases in cluster 2 were all from the Ravnice Grave. Cluster three was cases from Ravnice and Lazete 02 and cluster 4 was a sole case from Glogova 01. All cases had gunshot wounds as cause of death.

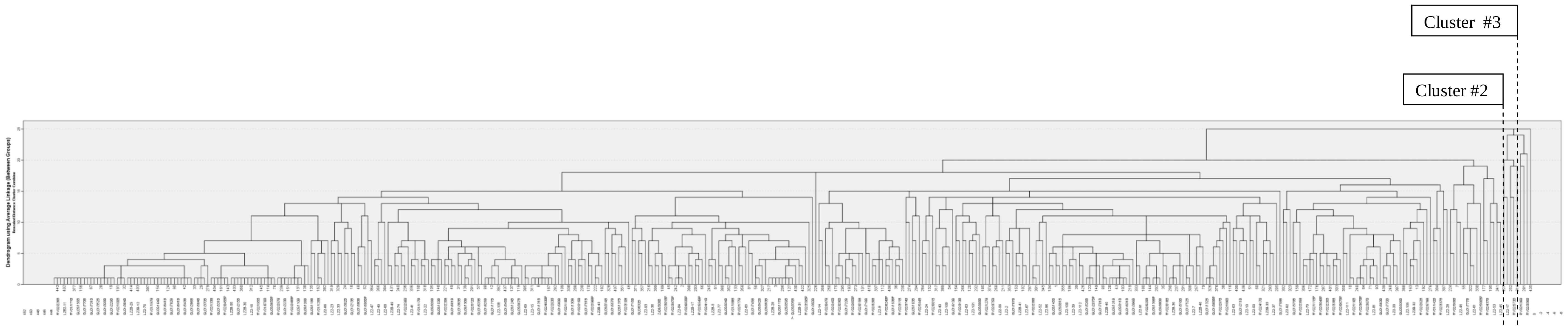
Cluster #3
Cluster #2
Dendrogram using Average Linkage (Between Groups)

Figure 6-6: Cluster analysis for gunshot wound cause of death group

6.3.2. Clustering cases of blast injury and gunshot wound deaths

To attempt to differentiate between the blast injury and the gunshot wound causes of death, cluster analysis was employed as a potential tool to do this. This section will present the results and the discussion chapter will address how this method can be used, its accuracy and potential in the analysis of blast trauma. All cluster analyses were performed using the binary squared Euclidean distance measure and the average linkage between groups method, as described in the Methods chapter.

The syntax used was as described in the methods chapter (Section 5.5.2). Initially, the cluster analysis was performed 5 times with random sampling and the output was produced for a larger number of solutions (from a 2 cluster solution to a 10 cluster solution, shown in Table 6-31) to identify the appropriate solution for this sample.

Using the agglomeration schedules to determine the appropriate number of clusters, the following was the resulting pattern.

Table 6-31: Optimal number of clusters based on random sampling of blast injury and gunshot wound cases over five trials. Coefficients based on agglomeration schedule. Numbers in parenthesis in coefficient column represent number of clusters corresponding to that solution.

Analysis #	Coefficients	Difference	# of clusters
1	10.658(1), 9.431(2)	1.227	2
2	9.816(3), 9.000(4)	0.816	4
3	10.474(1), 9.586(2)	1.161	2
4	12.362(1), 9.244(2)	3.118	2
5	10.733(1), 9.128(2)	1.605	2

As seen in these consecutively run cluster analyses, 2 clusters appears to be the optimal solution. Subsequently, the analysis was performed another 6 times to identify further 2 cluster solutions and determined if predominantly this was the solution which was present most often.

Table 6-32: Optimal number of clusters based on random sampling of blast injury and gunshot wound cases over six trials. Coefficients based on agglomeration schedule. Numbers in parenthesis in coefficient column represent number of clusters corresponding to that solution.

Analysis #	Coefficients	Difference	# of clusters
6	9.139(4), 8.116(5)	1.023	5
7	9.696(3), 8.193(4)	1.503	4
8	11.000(1), 9.845(2)	1.155	2
9	9.685(1), 8.490(2)	1.195	2
10	9.160(3), 7.917(4)	1.243	4
11	10.810(1), 9.000(2)	1.810	2

In the second series of cluster analyses, half of the solutions indicated 2 clusters and the other three, either 3, 4 or 5 clusters, shown in Table 6-32.

To be able to determine if the cluster analyses can differentiate between blast injury and gunshot wound deaths in a manner which can permit identification of trauma seen in an assemblage, the clusters were examined to determine what cases were present in the 2 cluster solutions.

Analysis #1

A total of 97 cases formed the first subsample, with all 48 cases of blast injury and 49 cases of gunshot wound trauma. The majority of cases were assigned to cluster one. There were two cases that were assigned to cluster #2, GL01/375B and GL01/541B. Both of these cases list cause of death as blast injury. No other cases of blast injury were found in a separate cluster to the gunshot wound cases.

Analysis #2

A total of 108 cases were subsampled for the analysis. The blast injury cases (N= 48) and the gunshot wound cases (N= 60) were analysed. The agglomeration schedule indicates a four cluster solution for this subsample.

Cluster 2: GL01/375B

Cluster 3:GL01/541B, RV02/314B, RV02/573B

Cluster 4: GL01/470B

The rest of the cases were assigned to cluster #1. Cluster 2 is a case with blast injury as the cause of death, as is cluster 4. Cluster three is composed of one case of blast injury and two of gunshot wound causes of death.

Analysis #3

This analysis was a subsample of 99 cases, with 48 of these being blast injury causes of death and 51 with gunshot wounds as the cause of death. As in the previous two analyses, the majority of the sample was clustered within the first cluster. The cases found in cluster two were GL01/375B and GL01/541B. Both of these have blast injury as cause of death and have also been previously singled out from the rest of the sample, as in Analysis #1.

Analysis #4

This analysis was comprised of 95 cases; of these 47 were the cases with gunshot wounds as the cause of death with the remainder being blast injury causes of death. The agglomeration schedule indicates a two cluster solution, with cluster membership assigning all cases but one to the first cluster. The second cluster is made of RV02/356B, a case with gunshot wounds listed as the cause of death. There was no differentiation of the blast injury cases from the gunshot wound cases.

Analysis #5

88 cases were analysed at this stage, 48 of these were classified as having blast injury as cause of death, with the remainder being gunshot wound cases. The agglomeration schedule indicates a two cluster solution, with cluster membership assigning all cases but two to the first cluster. The second cluster was composed of GL01/375B and GL01/541B, as in the first and third analyses. Both of these cases were listed as having blast injury as the sole cause of death. No other cases of blast injury were differentiated from the gunshot wound cause of death.

Analysis #6

According to the agglomeration schedule for this sample of 90 cases (42 gunshot wound cases, 48 blast injury), a five cluster solution is optimal. The first cluster is composed of the majority of cases and can be seen in the dendrogram. The following cases belong to the next four clusters:

Table 6-33: Analysis #6 showing the cases and causes of death for cases not belonging to cluster #1.

Case #	**Cluster**	**Cause of death**
RV02/532B	2	GSW
LZ2-50	2	GSW
RV02/566BP	2	GSW
GL01/470B	3	BI
GL01/484B	4	BI
GL01/607B	4	BI
GL01/619B	4	BI
ZJ06/616B	4	Unascertained
GL01/413B	4	BI
GL01/507B	4	BI
GL01/541B	5	BI

Analysis #7

This cluster analysis of the subsample included 98 cases, 48 of blast injury and 50 of gunshot wound causes of death. The agglomeration schedule indicates an optimal solution of four clusters, with the difference in coefficients being 1.503.

Table 6-34: Analysis #7 showing the cases and causes of death not belonging to cluster #1.

Case #	Cluster	Cause of death
GL01/470B	2	BI
GL01/507B	3	BI
RV02/126B	3	GSW
GL01/541B	3	BI
GL01/484B	4	BI
GL01/607B	4	BI

Analysis #8

For this analysis, 105 cases were randomly selected by SPSS using the syntax. There were 57 cases of gunshot wound deaths and 48 blast injury related deaths. The agglomeration schedule indicates an optimal solution of two clusters based on the difference in the coefficients between a one cluster solution and a two cluster solution. The difference is 1.155. The sole case which has been classified separately from the others is GL01/541B, a case of blast injury. All others were classified with no distinction by agglomeration.

Analysis #9

The random sampling produced a subsample of 105 cases, with 57 cases of gunshot wound deaths. The agglomeration schedule indicated a two cluster solution, with the difference between the coefficients 1.195. The following cases were clustered in the second cluster.

Table 6-35: Analysis #9 showing the cases and causes of death not belonging to cluster #1.

Case #	Cluster	Cause of death
GL01/413B	2	BI
GL01/541B	2	BI
GL01/484B	2	BI
GL01/507B	2	BI
GL01/607B	2	BI
GL01/619B	2	BI
ZJ06/616B	2	BI
LZ2-24	2	GSW
LZ2-45	2	GSW

Analysis #10

The cluster analysis was performed with a subsample of 99 cases (N= 51 gunshot wound cases). The agglomeration schedule produced an ideal clustering solution of 4 clusters. The difference between the coefficients was 1.243.

Table 6-36: Analysis #10 showing the cases and causes of death not belonging to cluster #1.

Case #	Cluster	Cause of Death
GL01/619B	2	BI
ZJ06/616B	2	Unascertained
GL01/413B	2	BI
GL01/507B	2	BI
GL01/484B	2	BI
GL01/607B	2	BI
GL01/331B	2	BI
GL01/470B	3	BI
GL01/541B	4	BI

Analysis #11

The analysis was conducted with a sample of 89 cases, 41 with a cause of death listed as gunshot wound. The agglomeration schedule indicates a solution of two clusters, with the difference in the coefficients being 1.810. Only two cases were isolated into the second cluster, GL01/375B and GL01/541B. The pathology reports for both these cases list blast injury as the cause of death.

6.3.3. Clustering body region variables- blast injury and gunshot wound deaths

To continue the analysis into the differentiation between blast injury and gunshot wound causes of death, investigation into the patterns with the variables was necessary. The first analysis was performed on the complete sample including all blast injury and gunshot wound cases, along with the unascertained causes of death and those having both blast injury and gunshot wounds combined as the cause of death. Subsequently, a second set of analyses were performed using the same subsampling routine as in 6.3.2. In all these analyses however, the variables as opposed to the cases were analysed.

Analysis #1

This analysis was performed on the entire sample set of blast injury and gunshot wound cases (N= 584). The binary squared Euclidean distance measure was employed and the average linkage between groups was the method. The agglomeration schedule produced in the output indicates a two cluster solution for the body region variables in this analysis. The coefficient difference between the one cluster solution (236.364) and the two cluster solution (211.053) is 25.311. The next largest difference in the agglomeration schedule is between a 22 and 23 cluster stage, with a difference between the coefficients of 26.167. By employing the coefficients to determine the ideal number of clusters, this analysis yields no patterns in the body region variables when examining the entire sample of 584 cases.

Analysis #2

This analysis was performed using the subsampling syntax as in section 6.3.2. The distance measure employed was binary squared Euclidean and the method was average distance between groups.

A total of 93 cases were clustered (N= 45 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a two cluster solution, with the difference between the single cluster and two cluster solution coefficients being 5.501.

Cluster #1 included the following body region variables: neurocranium, maxillofacial, mandible, left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, right side, left side, no side.

Cluster #2 included the following body region variables: vertebrae, left ribs, right ribs, and bilateral siding.

Analysis #3

The third analysis computed 90 cases to be clustered (N= 42 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a two cluster solution, with the difference between the single cluster and two cluster solution coefficients being 3.814.

Cluster #1 included the following body region variables: neurocranium, maxillofacial, mandible, left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left ribs, right ribs, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, right side, left side, no side.

Cluster #2 included the following body region variables: bilateral siding.

Analysis #4

The fourth analysis computed 99 cases to be clustered (N= 51 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a two cluster solution, with the difference between the single cluster and two cluster solution coefficients being 9.308.

Cluster #1 included the following body region variables: neurocranium, maxillofacial, mandible, vertebrae, left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left ribs, right ribs, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, right side, left side, no side.

Cluster #2 included the following body region variables: bilateral siding.

Analysis #5

The fifth analysis computed 86 cases to be clustered (N= 38 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a two cluster solution, with the difference between the single cluster and two cluster solution coefficients being 11.248.

Cluster #1 included the following body region variables: neurocranium, maxillofacial, mandible, vertebrae, left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left ribs, right ribs, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, right side, left side, no side.

Cluster #2 included the following body region variables: bilateral siding.

Analysis #6

The sixth analysis computed 98 cases to be clustered (N= 50 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a three cluster solution, with the difference between the two cluster and three cluster solution coefficients being 7.900.

Cluster #1: neurocranium, maxillofacial.

Cluster #2: mandible, left shoulder girdle, right shoulder girdle, left forearm, right forearm, left hand, right hand, vertebrae, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, left, right, no side.

Cluster #3: left ribs, right ribs, bilateral siding.

Analysis #7

The seventh analysis computed 88 cases to be clustered (N= 40 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a three cluster solution, with the difference between the two cluster and three cluster solution coefficients being 7.218.

Cluster #1: Neurocranium, maxillofacial, mandible, left shoulder girdle, right shoulder girdle, left forearm, right forearm, left hand, right hand, left pelvis, right pelvis, left femur, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, left, right, no side.

Cluster #2: Vertebrae, left ribs, right ribs, bilateral siding.

Analysis #8

The eighth analysis computed 96 cases to be clustered (N= 48 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a five cluster solution, with the difference between the four cluster and five cluster solution coefficients being 7.158.

Cluster #1: Neurocranium, maxillofacial.

Cluster #2: Mandible, left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left pelvis, right pelvis, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot, left side, right side, no side.

Cluster #3:Left ribs, right ribs.

Cluster #4: left femur.

Analysis #9

Contrary to the previous 8 analyses, the siding variables were not included in this part of the analysis. This will permit to ascertain if there are any patterns strictly concerning the body region variables. This was also performed using the subsampling syntax (as in section 6.3.2). This analysis used a subsample of 92 cases (N= 44 gunshot wound cases). The agglomeration schedule indicates a two cluster solution, with a coefficient difference of 7.845.

In this solution, all variables were clustered in the second cluster except for two variables, the neurocranium and maxillofacial variables which were clustered into the first cluster.

Analysis #10

The tenth analysis computed 99 cases to be clustered (N= 51 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a three cluster solution, with the difference between the two cluster and three cluster solution coefficients being 6.229. The body region variables are detailed for each cluster, below.

Cluster #1: Neurocranium, maxillofacial, mandible.

Cluster #2: Vertebrae, left ribs, right ribs.

Cluster #3: Left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left pelvis, right pelvis, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot.

Analysis #11

The eleventh analysis computed 90 cases to be clustered (N= 42 gunshot wound cases, N = 48 blast injury cases). The agglomeration schedule produced indicates a three cluster solution, with the difference between the two cluster and three cluster solution coefficients being 4.73. The body region variables are detailed for each cluster, below.

Cluster #1: Neurocranium, maxillofacial, mandible.

Cluster #2: Vertebrae, left ribs, right ribs.
Cluster #3: Left shoulder girdle, right shoulder girdle, left upper arm, right upper arm, left forearm, right forearm, left hand, right hand, left pelvis, right pelvis, right femur, left tibia and fibula, right tibia and fibula, left foot, right foot.

6.4. Multiple correspondence analysis

This analysis aims to identify associations in the variables between the blast injury and gunshot wound deaths. It is used to highlight the associations which can aid the recognition and differentiation between the two. The variables which this analysis identifies will serve as variables in a binary logistic regression whose aim is the prediction of cause of death membership, to differentiate blast injury from other causes of death in large-scale assemblages.

As outlined in the methods chapter (see section 5.5.3), the multiple correspondence analyses was performed using a syntax file which automates the process of randomly sampling from the gunshot wound cases to create a sample of even size between the blast injury cases and the gunshot wound cases. It is identical for each analysis. The analysis was undertaken 6 times, until the sampling and analysis yielded reproducible results in which the researcher could be confident.

The following reports the results of the multiple correspondence analyses.

6.4.1. Analysis #1

The first analysis was undertaken with 90 cases randomly subsampled (N= 42 gunshot wound cases). Changes were made to the syntax to produce plots which were not in a matrix format instead producing separate discrimination measure plots for dimensions 1 and 2 and then dimension 1 and 3 to enable clearer interpretation of the graphs.

Model summary

SPSS produced the following output summarising the analysis, Table 6-37: Multiple correspondence analysis model summary for Analysis #1.and Figure 6-7 and Figure 6-8.

Table 6-37: Multiple correspondence analysis model summary for Analysis #1.

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.686	2.886	.137	13.742
2	.600	2.333	.111	11.111
3	.533	2.030	.097	9.668
Total		7.249	.345	
Mean	.615[a]	2.416	.115	11.507
a. Mean Cronbach's Alpha is based on the mean Eigenvalue.				

The total variance accounted for across three dimensions is 34.521%.

Object scores labelled by cause of death

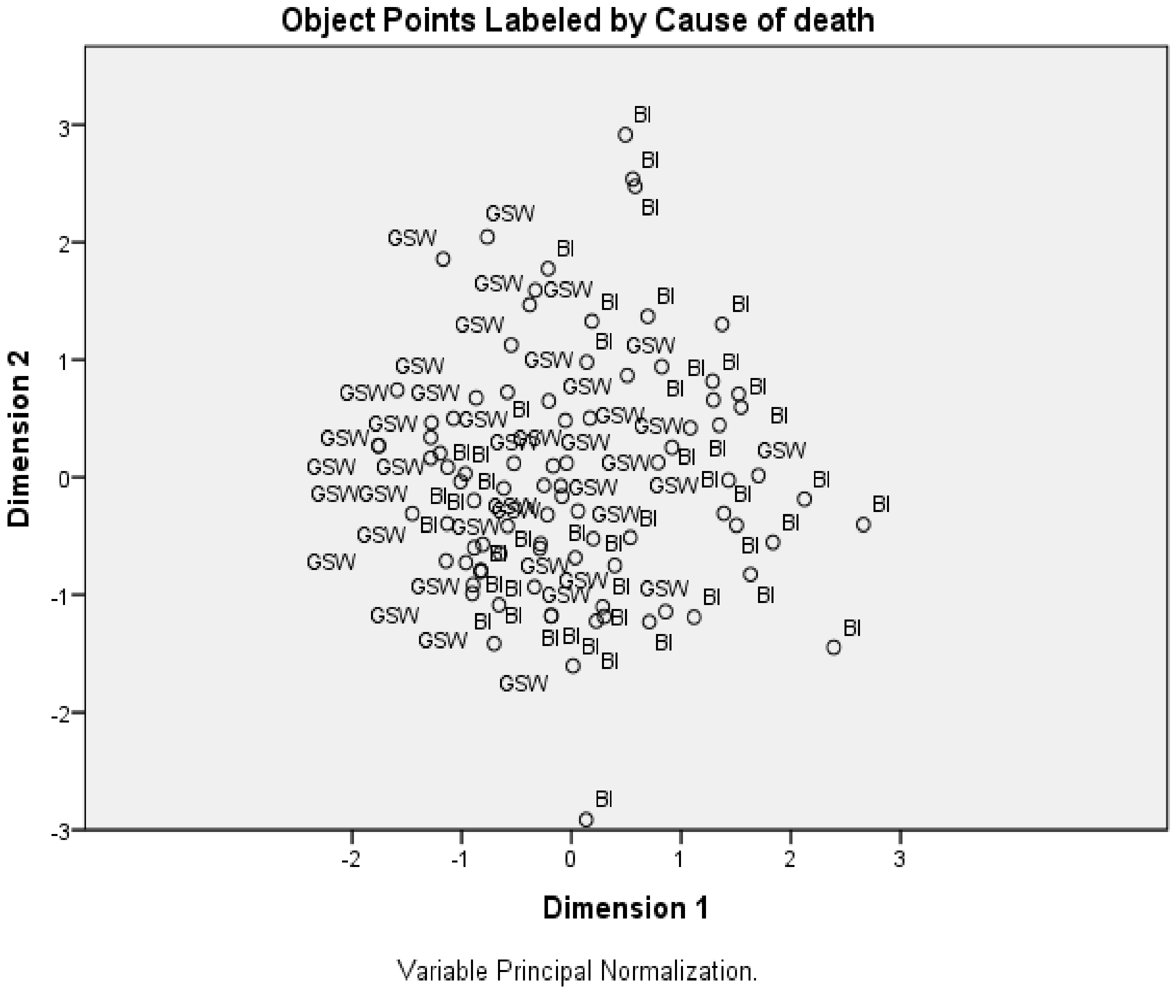

Figure 6-7: Object points labelled by cause of death, for dimensions 1 and 2. Dimension 1 shows a differentiation between the gunshot wound cases and the blast injury cases, with cases separated between the positive and negative sides of the axis.

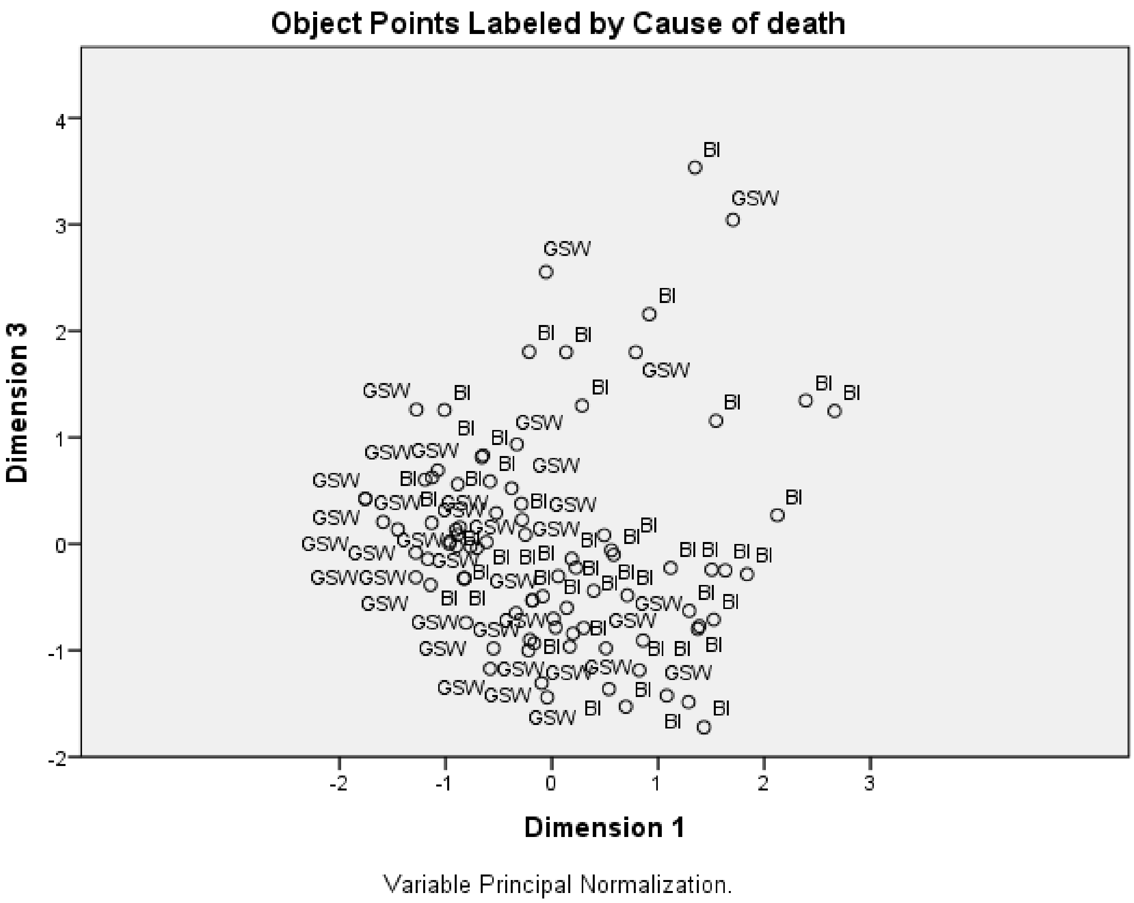

Figure 6-8: Object points labelled by cause of death for dimensions 1 and 3. Dimension 1 shows a differentiation along the axis, with separation of the blast injury on the positive side and gunshot wound cases on the negative side.

In both figure Figure 6-7: Object points labelled by cause of death, for dimensions 1 and 2 and Figure 6-8: Object points labelled by cause of death for dimensions 1 and 3, blast injury cases and gunshot wound cases can be seen on either side of the origin. Dimensions 1 and 2 appear to differentiate between the two causes of death better than dimensions 1 and 3. The majority of cases of gunshot wound deaths are clustered on the left side of the graph whilst the blast injury cases are on the right side. However, this is not a distinct separation of the two as cases from either cause of death can be found clustered in with the other on both sides of the origin.

Discrimination measures

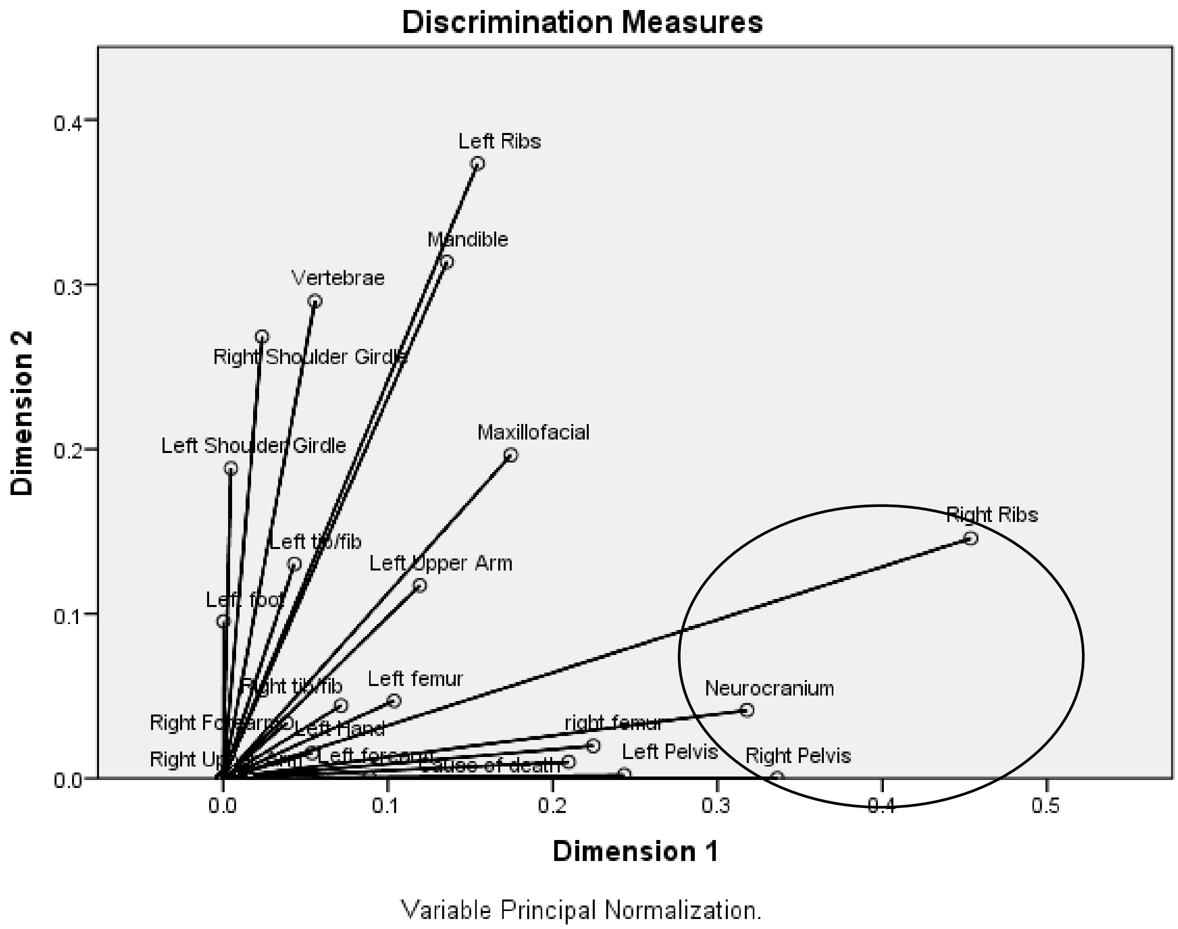

Figure 6-9: Discriminations measures for body region variables on dimensions 1 and 2. The discriminating variables on Dimension 1 which discriminate between gunshot and blast injury cases are the neurocranium, right ribs and right pelvis (circled).

The graphical representation of the body region variables in the discrimination measures plots , Figure 6-9 and Figure 6-10, demonstrate visually the variables which have the most discrimination power between the categories. In the previous figure, the body regions which discriminate and contribute most variance to dimension 1 are the neurocranium, right ribs, right femur, left pelvis and right pelvis. These have been circled for identification.

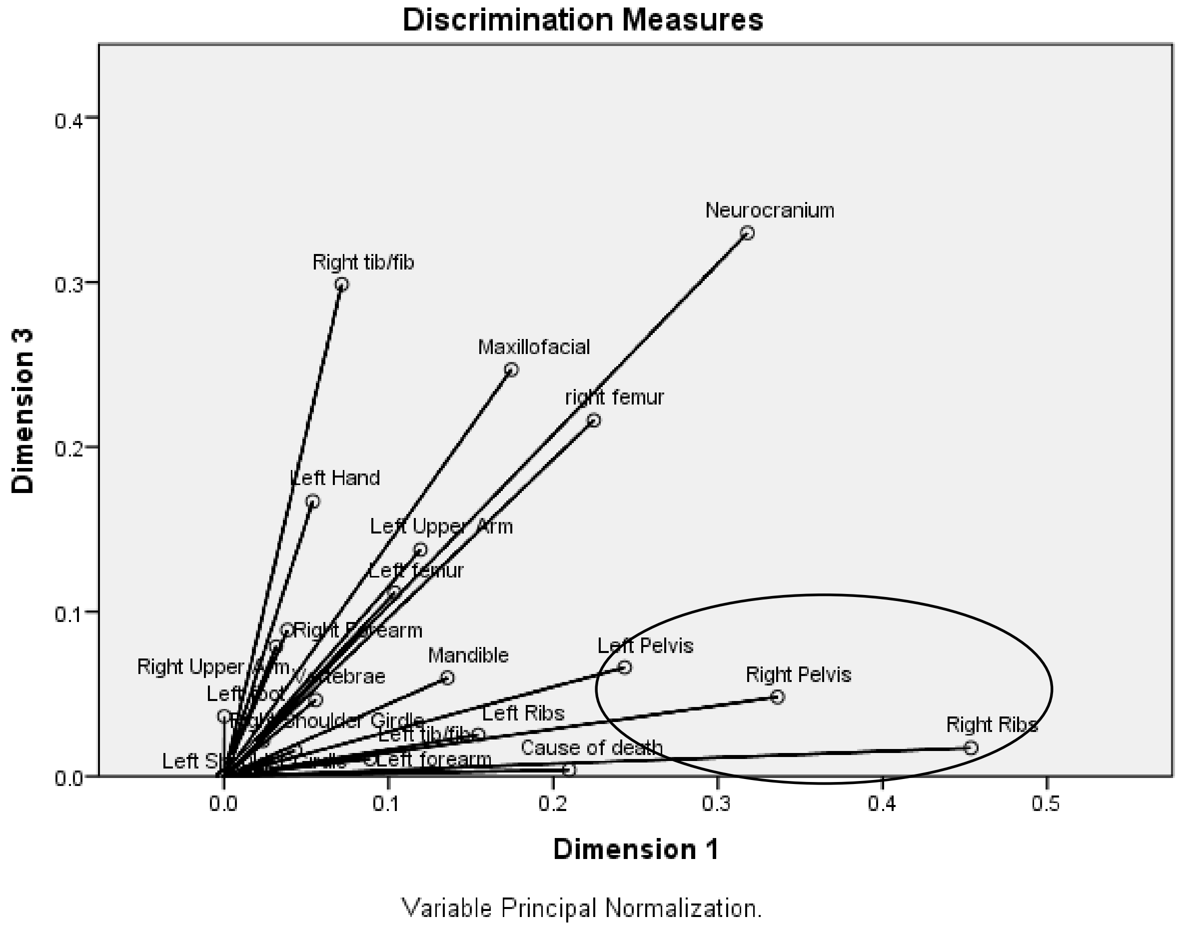

Figure 6-10: Discrimination measures for body region variables on dimensions 1 and 3. The discriminating variables on Dimension 1 which discriminate between gunshot and blast injury cases are the right ribs and the left and right pelvis (circled).

The figure for dimensions 1 and 3 showed similar variables as to those seen in the discrimination plot for dimensions 1 and 2. Dimension 1 was found to have the discriminating variables of right ribs, right pelvis, and left pelvis. Table 6-38: Discrimination measures for analysis #1. Variables which discriminate most between categories are highlighted. The variables which discriminate between the blast injury and gunshot cases are identified in bold. identifies the discrimination measures numerically with their contribution to the variance.

Table 6-38: Discrimination measures for analysis #1. Variables which discriminate most between categories are highlighted. The variables which discriminate between the blast injury and gunshot cases are identified in bold.

Discrimination Measures				
	Dimension			
	1	2	3	Mean
Cause of death	.210	.010	.004	.075
Neurocranium	**.318**	.041	.330	.230
Maxillofacial	.175	.196	.247	.206
Mandible	.136	.314	.060	.170
Vertebrae	.056	.290	.046	.131
Left Shoulder Girdle	.005	.188	.004	.066
Right Shoulder Girdle	.024	.268	.021	.104
Left Upper Arm	.119	.117	.138	.125
Right Upper Arm	.032	.000	.079	.037
Left forearm	.089	.000	.010	.033
Right Forearm	.039	.034	.089	.054
Left Hand	.054	.015	.167	.079
Left Ribs	.154	.373	.025	.184
Right Ribs	**.454**	.146	.017	.206
Left Pelvis	**.243**	.002	.066	.104
Right Pelvis	**.336**	.000	.048	.128
Left femur	.104	.047	.112	.088
Right femur	**.225**	.020	.216	.154
Left tib/fib	.043	.130	.016	.063
Right tib/fib	.072	.044	.299	.138
Left foot	.000	.095	.036	.044
Active Total	2.886	2.333	2.030	2.416
% of Variance	13.742	11.111	9.668	11.507

6.4.2. **Analysis #2**

The second multiple correspondence analysis was performed with a random subsample of 100 cases (N = 52 gunshot wound cases).

Model summary

Table 6-39: Multiple correspondence analysis model summary for Analysis #2.

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.710	3.090	.147	14.712
2	.617	2.426	.116	11.554
3	.512	1.952	.093	9.294
Total		7.468	.356	
Mean	.628[a]	2.489	.119	11.853

a. Mean Cronbach's Alpha is based on the mean Eigenvalue.

The three dimensions of the model account for 35.56% of the variance in the samples shown in Table 6-39: Multiple correspondence analysis model summary for Analysis #2.

Object scores labelled by cause of death

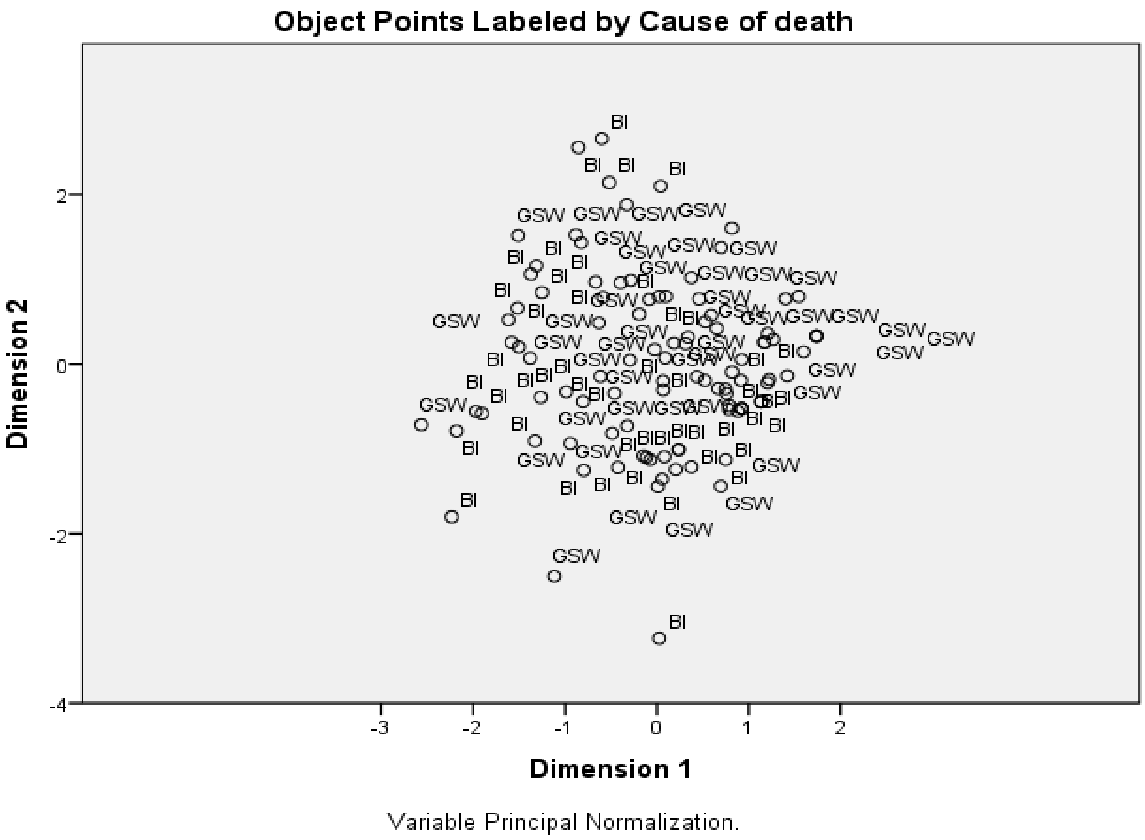

Figure 6-11: Object points labelled by cause of death for dimensions 1 and 2. No distinct differentiation between blast injury and gunshot wound cases is seen on either Dimension 1 or 2.

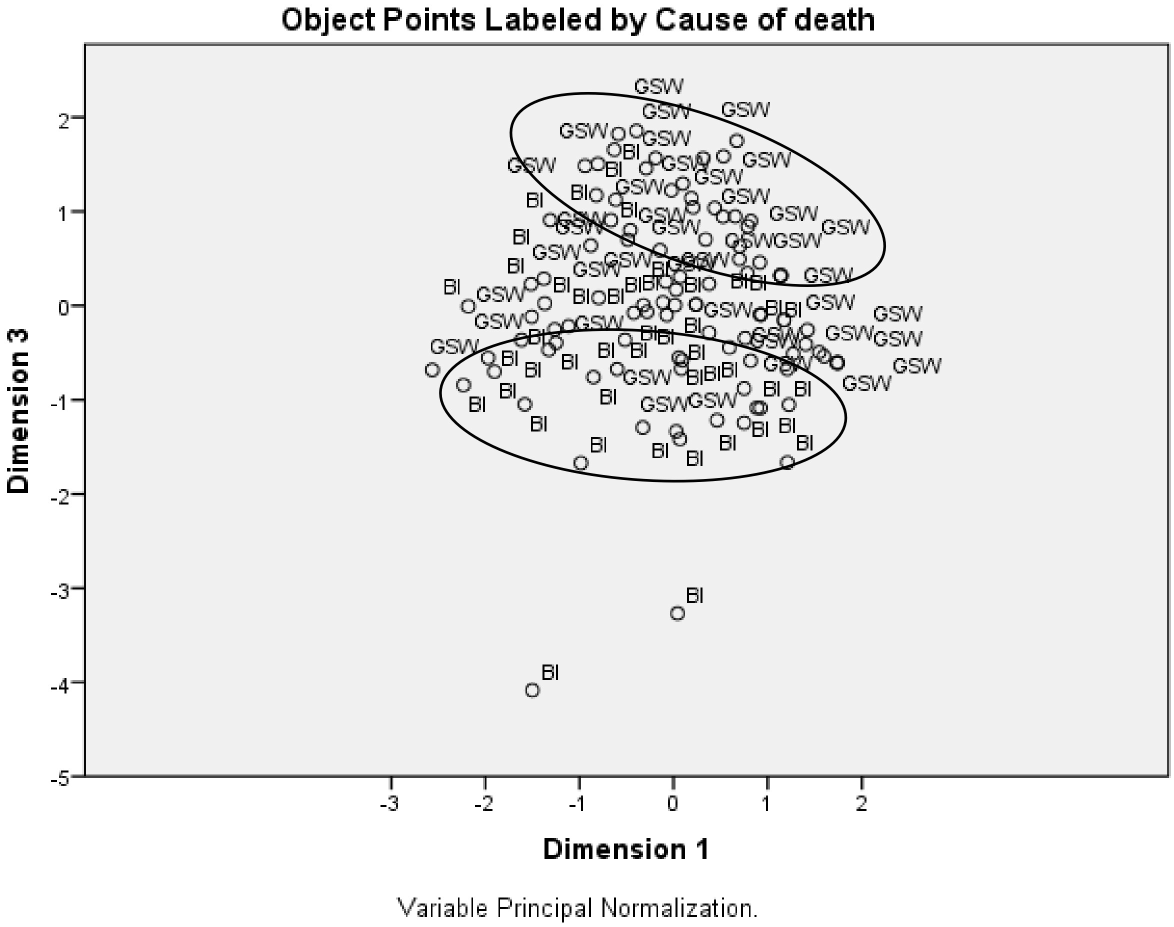

Figure 6-12: Object points labelled by cause of death for dimensions 1 and 3. Differentiation is more distinct on Dimension 3, with gunshot wound cases clustering at the positive end of the axis and blast injury at the negative end.

The plots of object points show some differentiation on dimensions 1 and 3, shown in

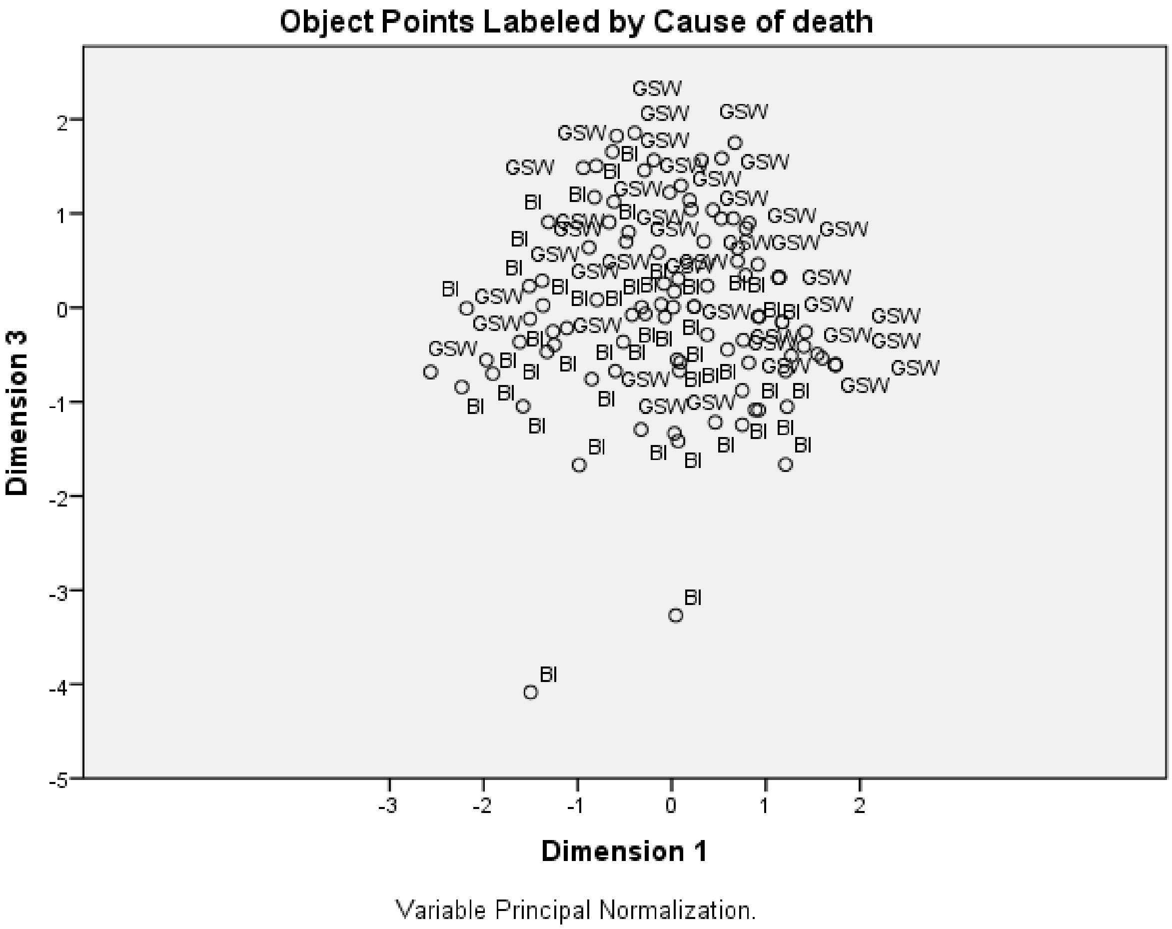

Figure 6-12: Object points labelled by cause of death for dimensions 1 and 3. Differentiation is more distinct on Dimension 3, with gunshot wound cases clustering at the positive end of the axis and blast injury at the negative end. . In dimensions 1 and 3, a concentration of gunshot wound cases can be seen on the right side of the graph, along with a cluster of blast injury cases towards the bottom of the graph. Dimension 3 differentiates blast injury from gunshot wound cases, with gunshot cases at the top and blast injury at the bottom.

Discrimination measures

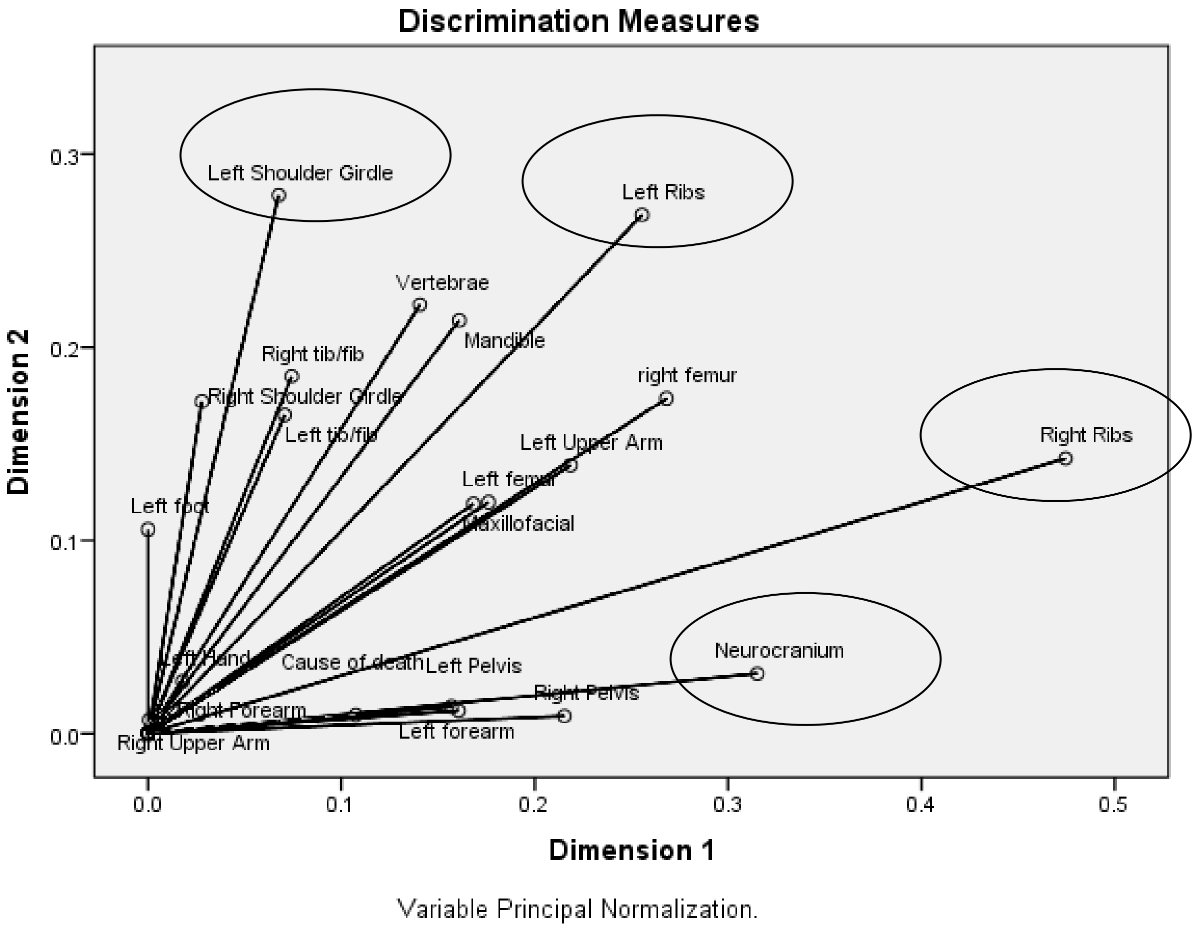

Figure 6-13: Discrimination measures for analysis #2 between dimensions 1 and 2. Important variables on Dimension 1 are the neurocranium and the right ribs.

On these two dimensions, only a few body region variables indicate that they contribute most of the variance as all others are closer to the origin and are not far apart from each other, seen in

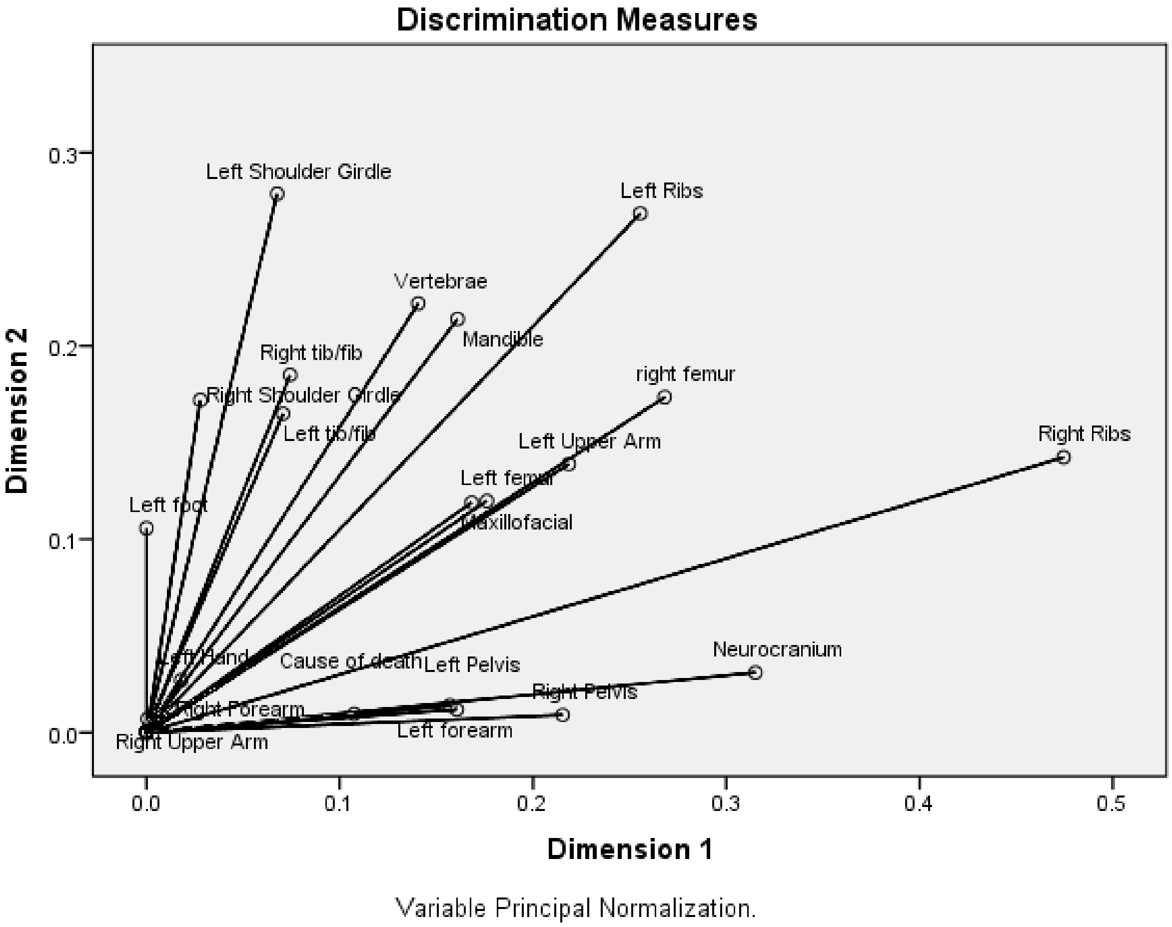

Figure 6-13: Discrimination measures for analysis #2 between dimensions 1 and 2. Important variables on Dimension 1 are the neurocranium and the right ribs.. On dimension 1, neurocranium and right ribs exhibit the largest contribution to variance. On dimension two, left shoulder girdle and left ribs contribute most.

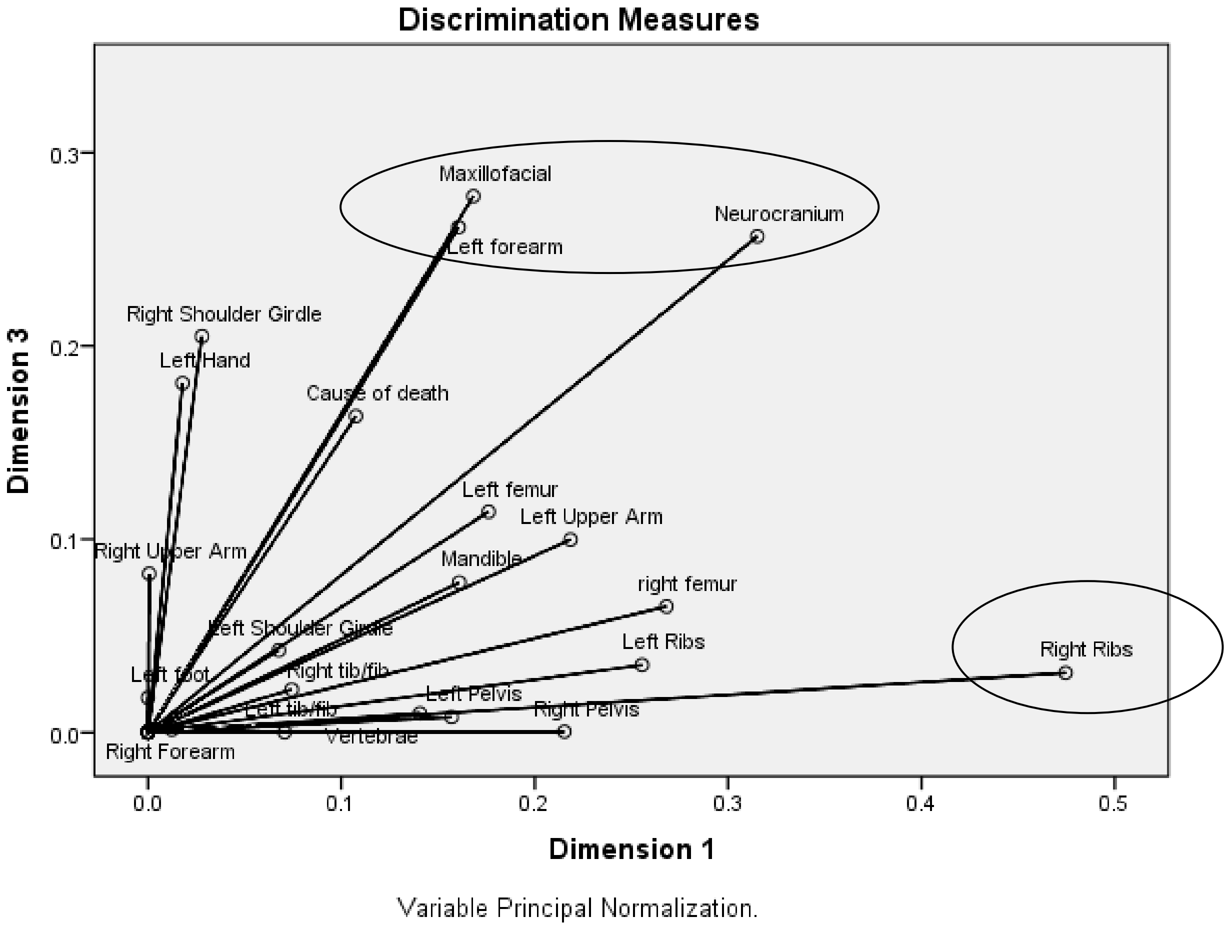

Figure 6-14: Discrimination measures for analysis #2 on dimensions 1 and 3. In this case, the right ribs contribute most variance to Dimension 1. Additionally, the maxillofacial neurocranium and left forearm variables contribute variance on Dimension 3 while contributing as well to Dimension 1.

In Figure 6-14: Discrimination measures for analysis #2 on dimensions 1 and 3, right ribs exhibits the largest contribution to variance on dimension 1. For dimension 3, right maxillofacial, left forearm and neurocranium variables are those which discriminate most. This is also shown in Table 6-40, with the measures highlighted for each dimension.

Table 6-40: Discrimination measures for analysis #2. Variables which discriminate between blast injury and gunshot wound cases are shown in bold for Dimensions 1 and 3.

Discrimination Measures				
	Dimension			
	1	2	3	Mean
Cause of death	.107	.010	.164	.094
Neurocranium	**.315**	.031	**.257**	.201
Maxillofacial	.168	.119	**.277**	.188
Mandible	.161	.214	.078	.151
Vertebrae	.141	.222	.010	.124
Left Shoulder Girdle	.068	.279	.042	.130
Right Shoulder Girdle	.028	.172	.205	.135
Left Upper Arm	.218	.139	.100	.152
Right Upper Arm	.001	.007	.082	.030
Left forearm	.161	.012	**.261**	.145
Right Forearm	.012	.013	.001	.009
Left Hand	.018	.027	.181	.075
Left Ribs	.256	.268	.035	.186
Right Ribs	**.475**	.142	.031	.216
Left Pelvis	.157	.014	.008	.060
Right Pelvis	.215	.009	.000	.075
Left femur	.176	.120	.114	.137
right femur	.268	.173	.065	.169
Left tib/fib	.071	.165	.000	.079
Right tib/fib	.074	.185	.022	.094
Left foot	.000	.106	.018	.041
Active Total	3.090	2.426	1.952	2.489
% of Variance	14.712	11.554	9.294	11.853

6.4.3. Analysis #3

The third analysis was undertaken with 81 cases (N = 33 gunshot wound cases).

Model summary

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.663	2.714	.129	12.922
2	.615	2.415	.115	11.500
3	.560	2.143	.102	10.206
Total		7.272	.346	
Mean	.617[a]	2.424	.115	11.543
a. Mean Cronbach's Alpha is based on the mean Eigenvalue.				

Table 6-41: Multiple correspondence analysis model summary for Analysis #3

The model in analysis #3 accounts for a total of 34.628% of the variance in the samples, shown in Table 6-41

Object scores labelled by cause of death

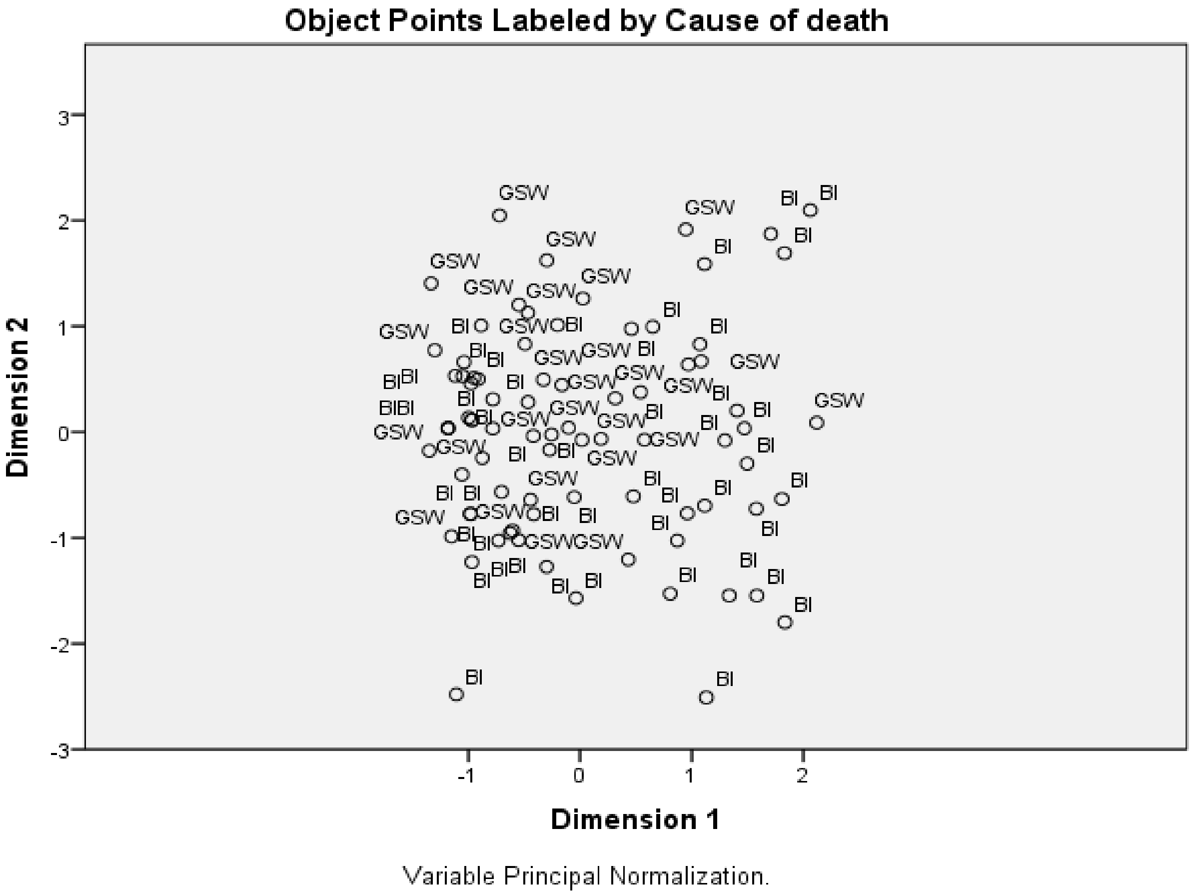

Figure 6-15: Object points labelled by cause of death for dimensions 1 and 2.

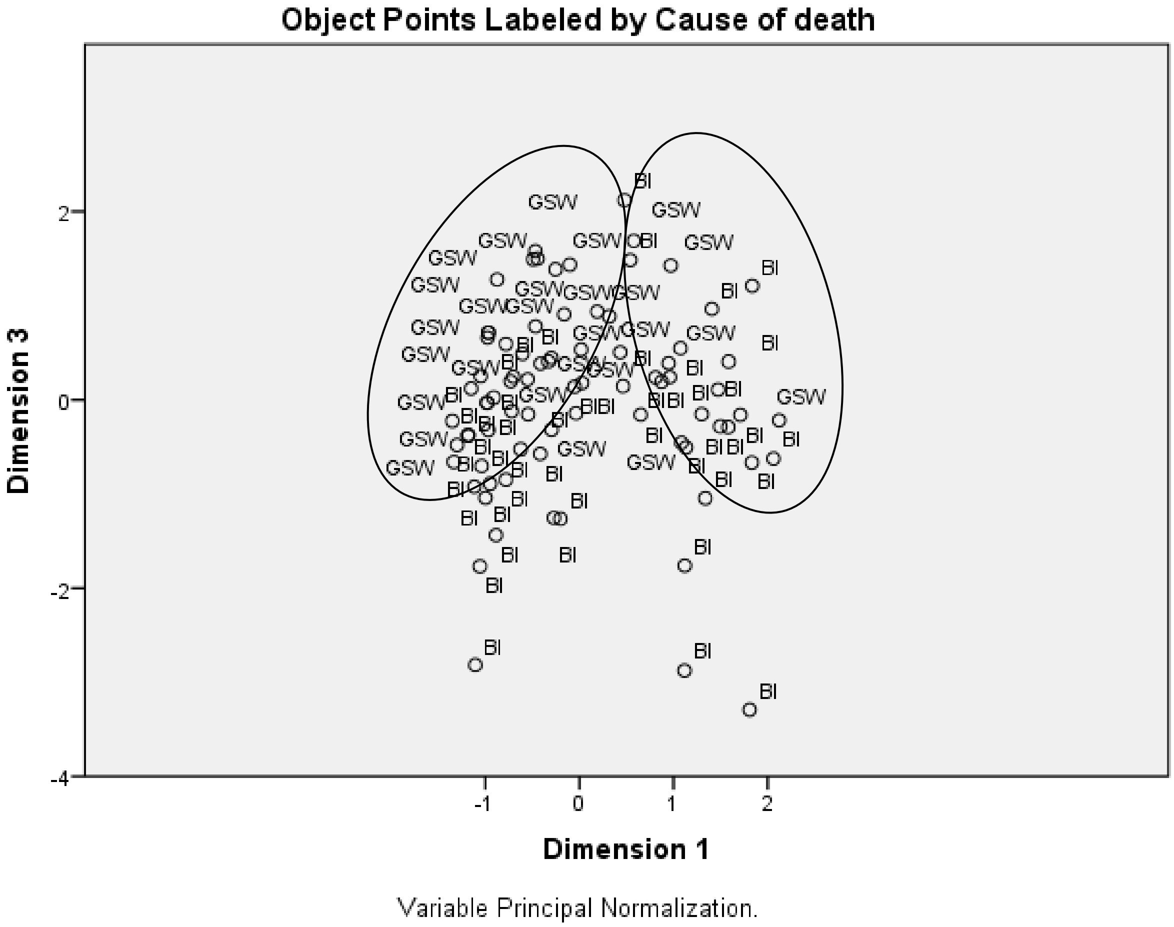

Figure 6-16: Object points labelled by cause of death for dimensions 1 and 3. Dimensions 1 shows differentiation with gunshot wound cases on the negative side of the axis and blast injury on the positive.

Examining the object score plots in for analysis #3, Figure 6-15 and Figure 6-16, no pattern differentiating between the two causes of death can been seen in the comparison between dimensions 1 and 2. Dimensions 1 and 3 differentiate between the two causes of death on the first dimension. Additionally two clusters of blast injury cases are found on the negative side of the dimension 3 axis.

Discrimination measures

The following discrimination measure plots were produced for analysis #3.

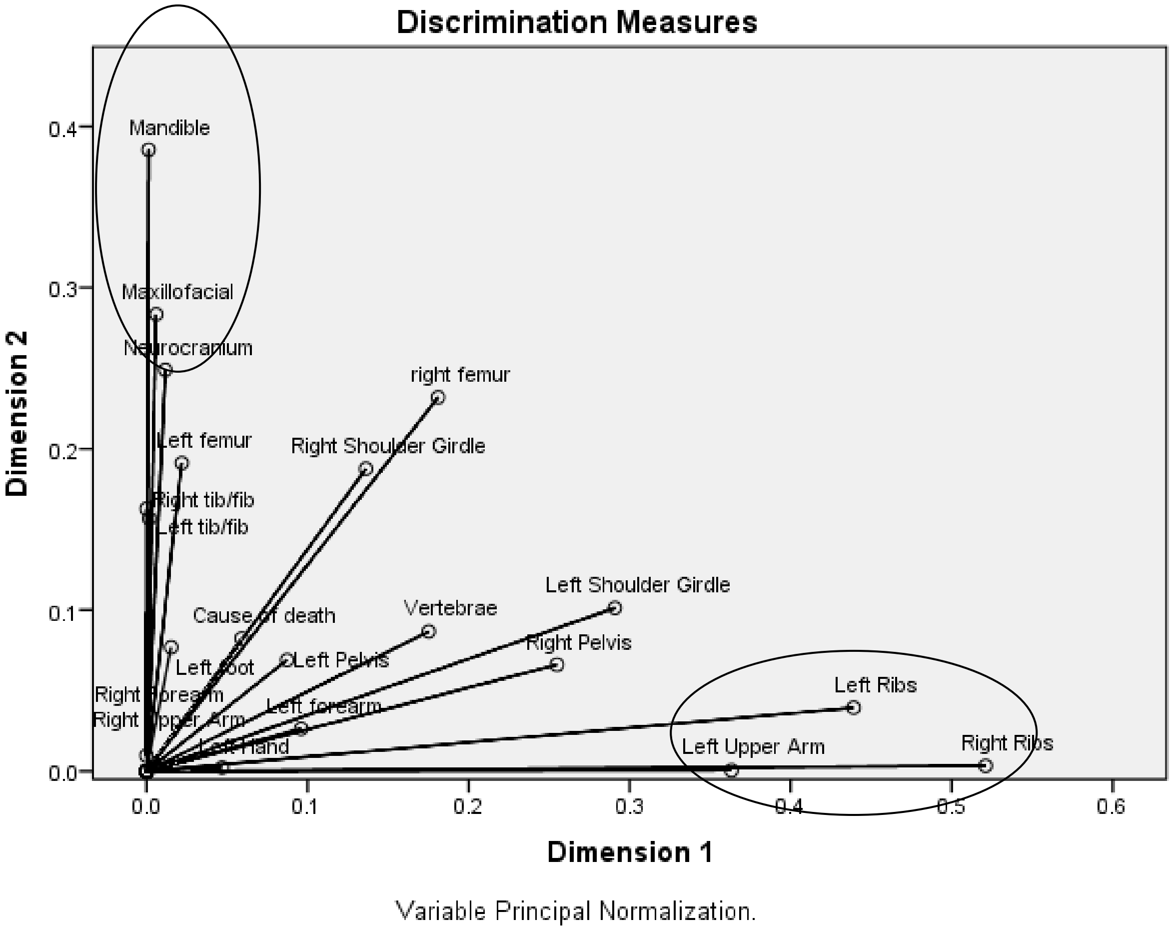

Figure 6-17: Discrimination measures for analysis #3 between dimensions 1 and 2. The largest amount of variance in Dimension 1 is accounted for by the left upper arm and left and right rib variables.

In this analysis, multiple body region variables were found to discriminate on both dimension 1 and 2, shown in Figure 6-17. On dimension 1, left upper arm, left ribs and right ribs were the variables which contribute most to the variance. On dimension two, mandible, maxillofacial and neurocranium variables exhibit the largest contribution to the variance in the sample, however this dimension was not found to differentiate between gunshot wound and blast injury cases.

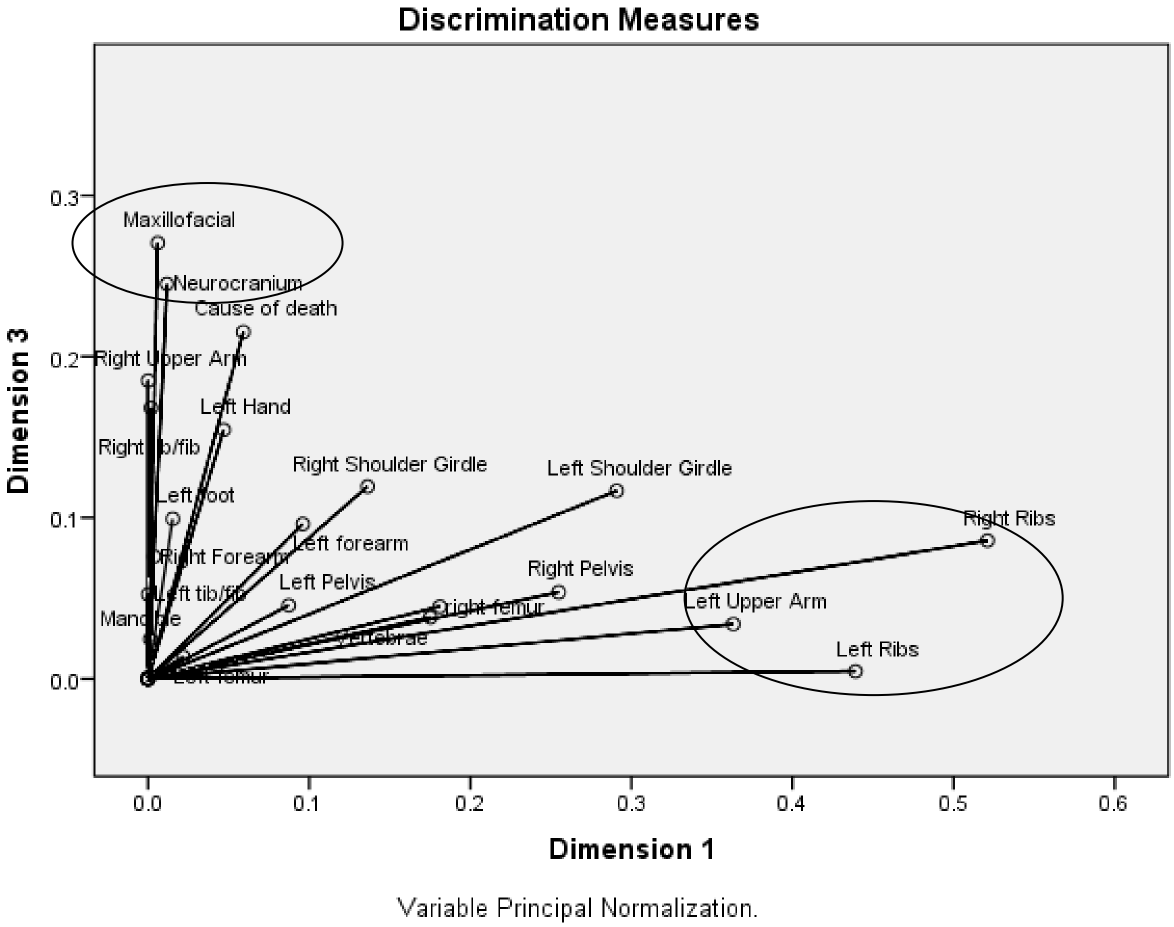

Figure 6-18: Discrimination measures for analysis #3 between dimensions 1 and 3. Dimension 1 variance is attributed to three highly contributing variables, the left upper arm and left and right ribs.

Shown in Figure 6-18, as in the previous figure, left upper arm, right ribs and left ribs differentiate between categories on dimension 1. For dimension three, maxillofacial and neurocranium body region variables are most important in the contribution to the variance of this dimension. Inertia values are presented in Table 6-42.

Table 6-42: Discrimination measures for analysis #3. Important variables on Dimension 1 are shown in bold.

Discrimination Measures				
	Dimension			
	1	2	3	Mean
Cause of death	.059	.082	.215	.119
Neurocranium	.012	.249	.245	.169
Maxillofacial	.006	.283	.270	.187
Mandible	.001	.386	.025	.137
Vertebrae	.175	.087	.038	.100
Left Shoulder Girdle	.291	.101	.117	.170
Right Shoulder Girdle	.136	.188	.119	.148
Left Upper Arm	**.363**	.001	.034	.133
Right Upper Arm	.000	.010	.185	.065
Left forearm	.096	.026	.096	.073
Right Forearm	.004	.003	.076	.027
Left Hand	.047	.002	.154	.068
Left Ribs	**.439**	.039	.005	.161
Right Ribs	**.521**	.003	.086	.203
Left Pelvis	.087	.069	.046	.067
Right Pelvis	.255	.066	.054	.125
Left femur	.022	.191	.014	.076
right femur	.181	.232	.045	.153
Left tib/fib	.000	.163	.052	.072
Right tib/fib	.002	.157	.168	.109
Left foot	.015	.077	.099	.064
Active Total	2.714	2.415	2.143	2.424
% of Variance	12.922	11.500	10.206	11.543

6.4.4. Analysis #4

This analysis was undertaken with 102 cases (N = 54 gunshot wound cases).

Model Summary

The following table represents the model summary for analysis #4, quantifying the variance accounted for on each of three dimensions, in Table 6-43.

Table 6-43: Multiple correspondence analysis model summary for Analysis #4.

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.686	2.888	.138	13.754
2	.625	2.469	.118	11.759
3	.488	1.870	.089	8.905
Total		7.228	.344	
Mean	.614[a]	2.409	.115	11.473
a. Mean Cronbach's Alpha is based on the mean Eigenvalue.				

The total variance accounted for by model #4 is 34.418%, consistent with the previous four models.

Object scores labelled by cause of death

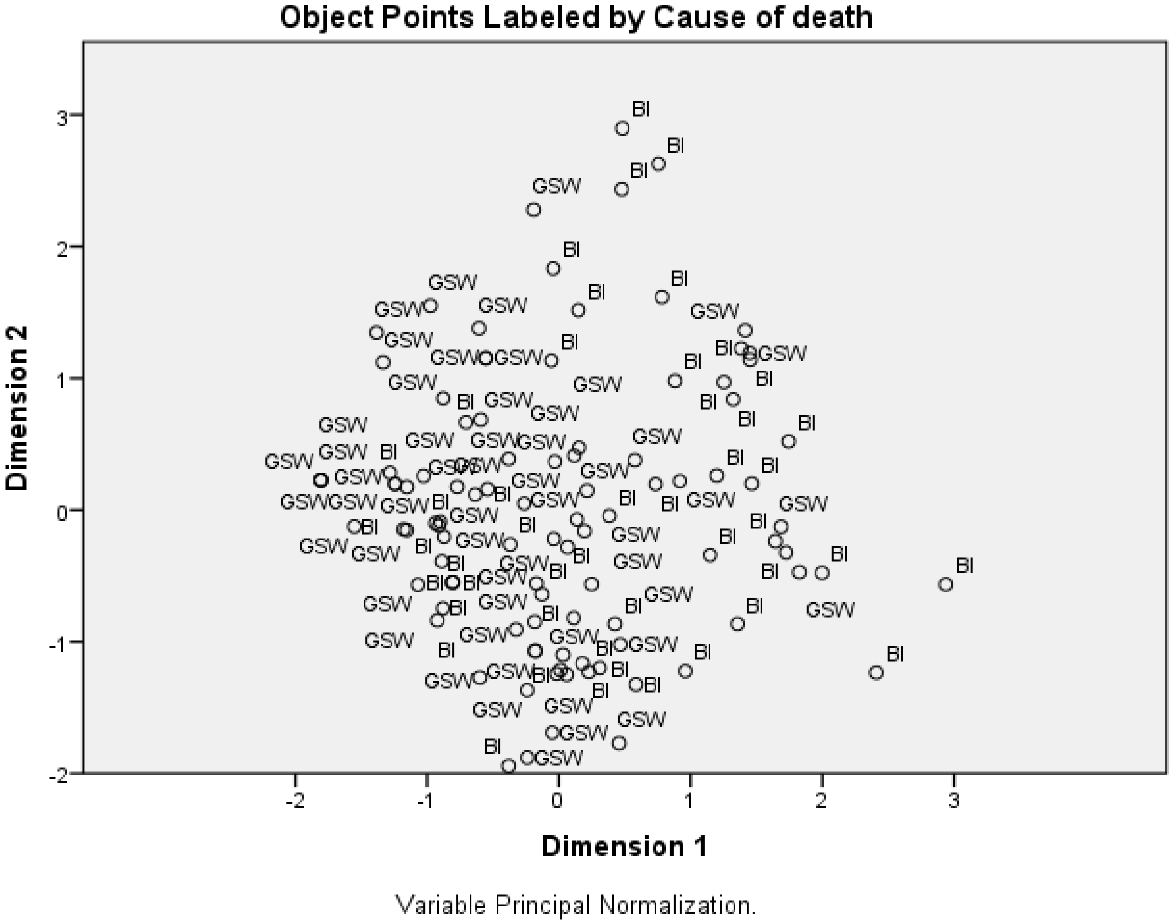

Figure 6-19: Object points labelled by cause of death for dimensions 1 and 2. No distinct differentiation can be seen in the cloud of points.

Dimension 1 and dimension 2 do not distinctly differentiate between the two causes of death, with a mix of both causes of death in the cloud points, shown in

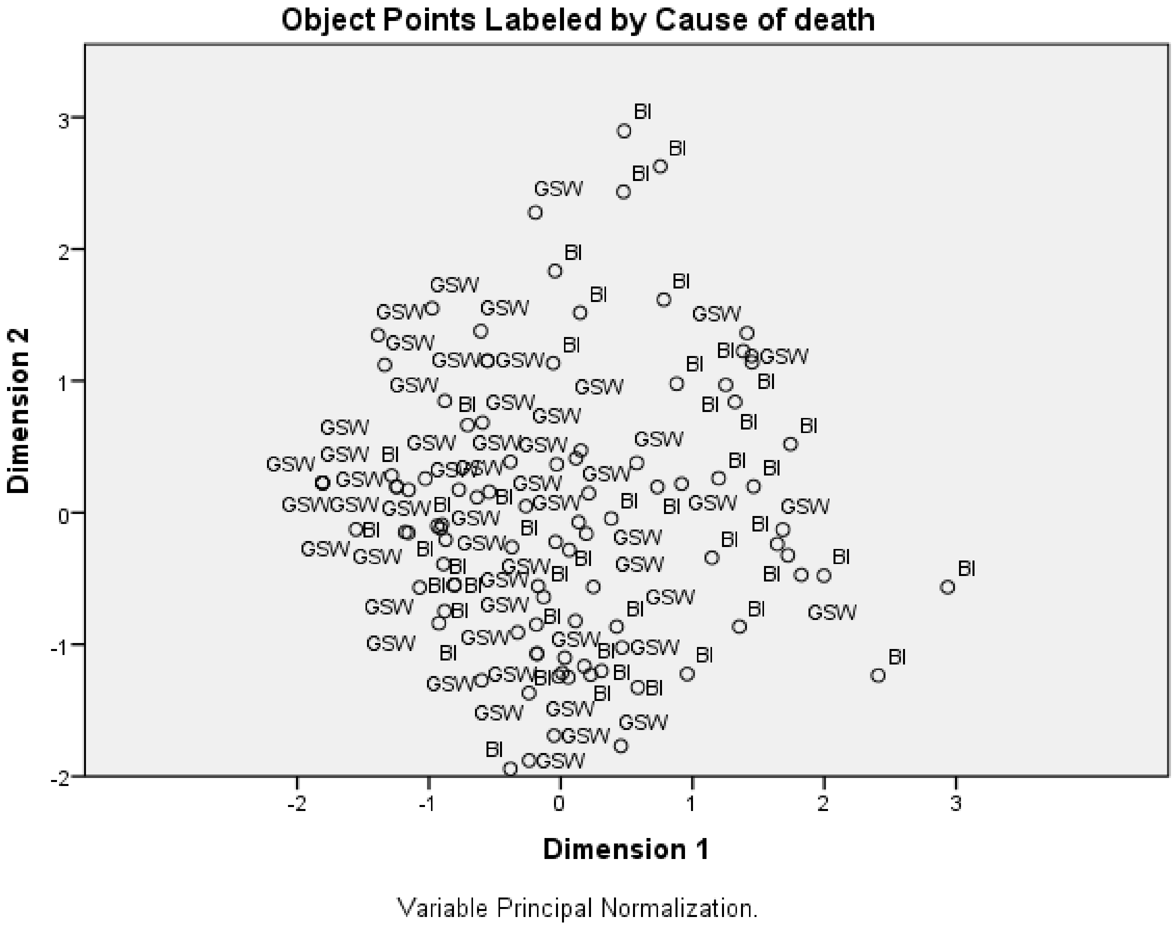

Figure 6-19. There is a tendency for the cases of gunshot wound deaths to cluster towards the left side of dimension 1, but show no pattern on dimension 2.

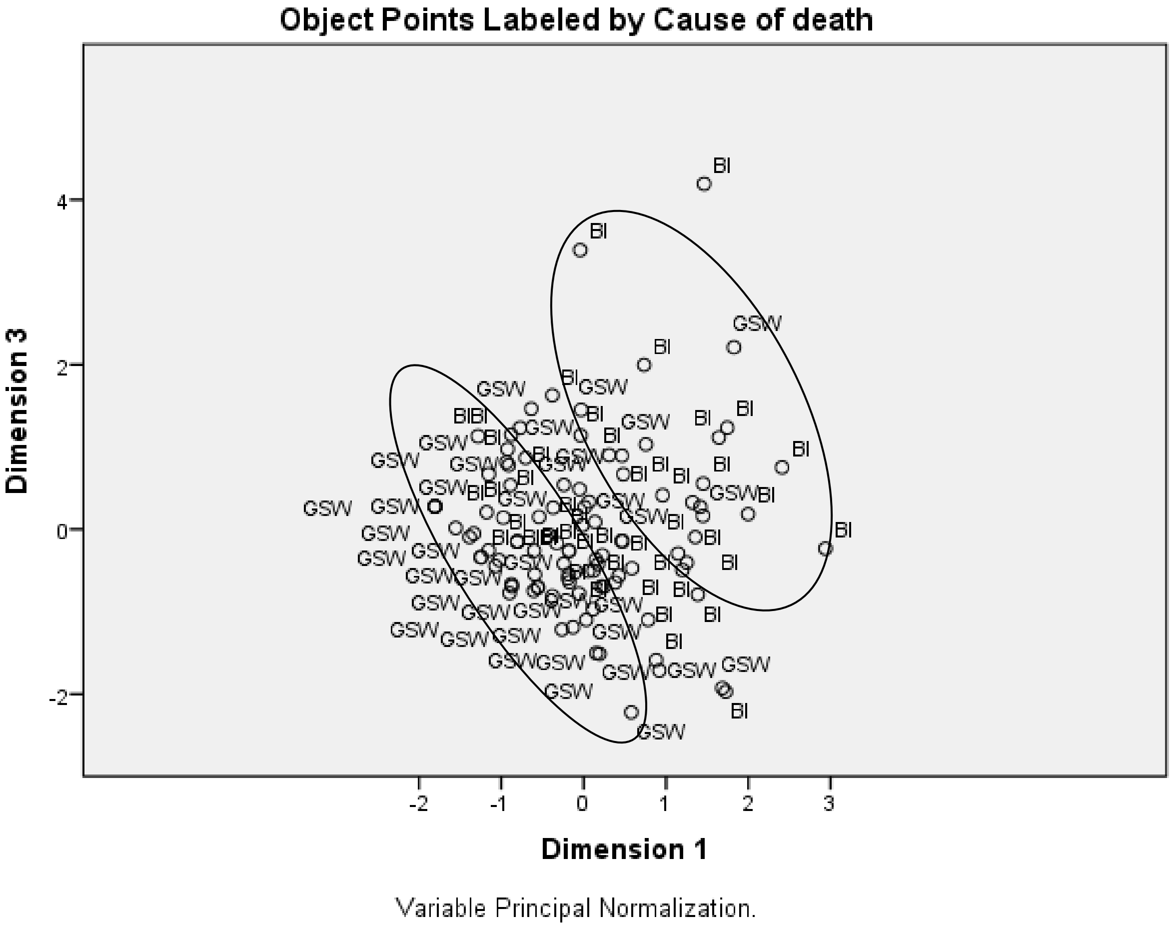

Figure 6-20: Object points labelled by cause of death for dimensions 1 and 3

In Figure 6-20, there is a differentiation between the causes of death on dimension 1, with the blast injury cases clustering on the positive side of the axis and the gunshot cases on the negative side. There appears to be no differentiation on dimension 3.

Discrimination measures

The following figures demonstrate the body region variables which discriminate on each of three dimensions.

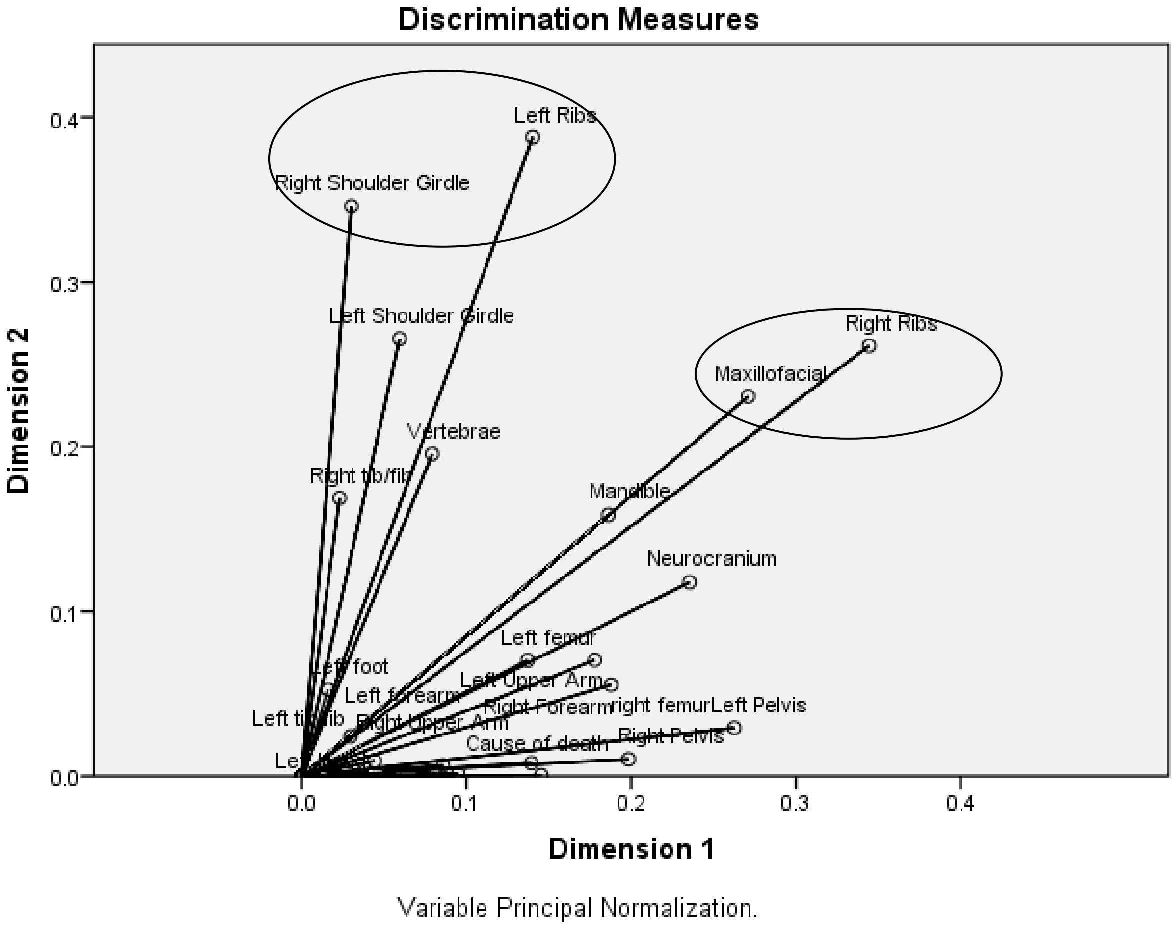

Figure 6-21: Discrimination measures for analysis #4 between Dimensions 1 and 2

On dimension 1 in

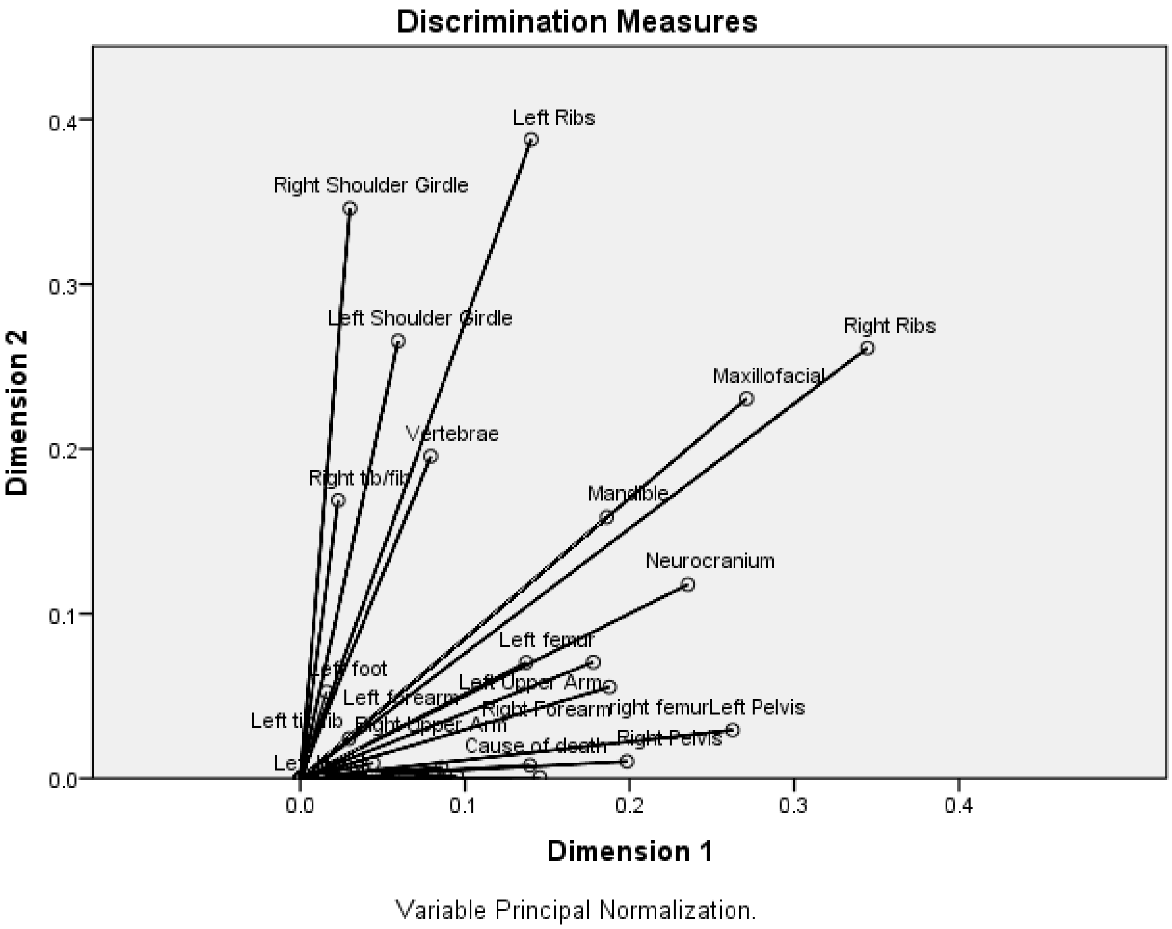

Figure 6-21, the only variables which account for most variance are the maxillofacial and right ribs variable. These however do not differentiate greatly on this dimension and contribute to dimension 2 as well. On dimension 2, the right shoulder girdle and the left ribs contribute most to the variance of the dimension however these do not differentiate between the causes of death.

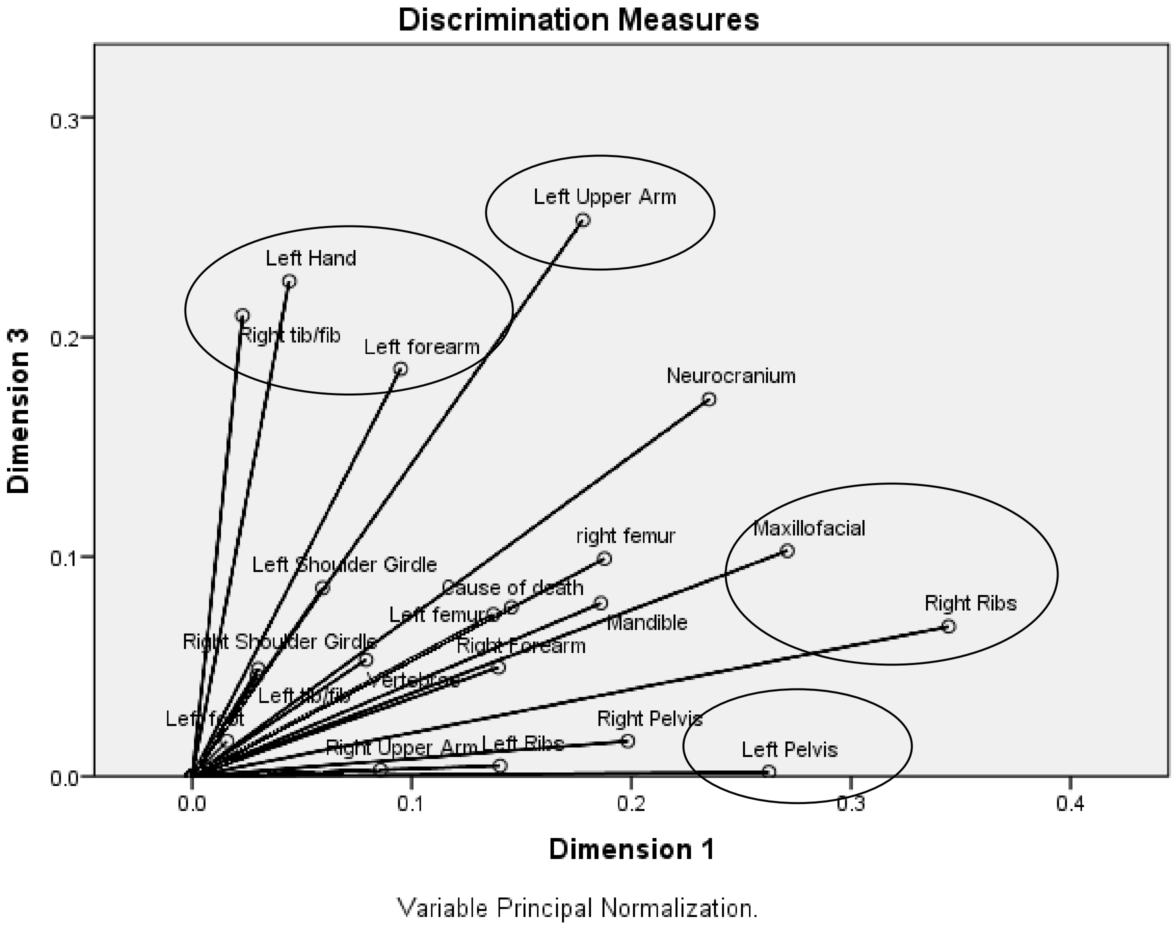

Figure 6-22: Discrimination measures for analysis #4 between dimensions 1 and 3. The maxillofacial, right ribs and left pelvis variables account for most variance on Dimension 1.

As in Figure 6-21: Discrimination measures for analysis #4 between Dimensions 1 and 2 , the maxillofacial, right ribs and left pelvis body region variables contribute most to dimension 1. On dimension 3, the variables of left upper arm, left hand, right tibia and fibula and left forearm differentiate from those on dimension 1. Dimension 1 was identified as differentiating between the two causes of death.

The values for each of the body region variables in the discrimination measures output is presented below in Table 6-44.

Table 6-44: Discrimination measures for analysis #4. Variables in bold account for the most variance on Dimension 1, which differentiate between causes of death.

Discrimination Measures				
	Dimension			
	1	2	3	Mean
Cause of death	.145	.001	.077	.074
Neurocranium	.235	.118	.172	.175
Maxillofacial	.271	.231	.103	.201
Mandible	.186	.159	.079	.141
Vertebrae	.079	.196	.053	.109
Left Shoulder Girdle	.059	.265	.086	.137
Right Shoulder Girdle	.030	.346	.049	.142
Left Upper Arm	.178	.070	.253	.167
Right Upper Arm	.086	.007	.003	.032
Left forearm	.095	.001	.186	.094
Right Forearm	.139	.008	.050	.066
Left Hand	.044	.009	.225	.093
Left Ribs	.140	.388	.005	.178
Right Ribs	.344	.261	.068	.225
Left Pelvis	.263	.029	.002	.098
Right Pelvis	.198	.010	.016	.075
Left femur	.137	.070	.074	.094
right femur	.188	.055	.099	.114
Left tib/fib	.030	.024	.046	.033
Right tib/fib	.023	.169	.210	.134
Left foot	.016	.052	.016	.028
Active Total	2.888	2.469	1.870	2.409
% of Variance	13.754	11.759	8.905	11.473

6.4.5. **Analysis #5**

In the fifth analysis undertaken, the random sampling syntax produced a combined sample of 79 cases (N= 31 gunshot wound cases).

Model summary

The model summary presented in represents the three dimensions along with the percentage of variance which can be explained in the sample by these.

Table 6-45: Model summary for analysis #5.

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.691	2.927	.139	13.939
2	.618	2.429	.116	11.565
3	.487	1.867	.089	8.888
Total		7.222	.344	
Mean	.614[a]	2.407	.115	11.464
a. Mean Cronbach's Alpha is based on the mean Eigenvalue.				

The total variance for the three dimensions in the model account for 34.393% of the variance, shown in Table 6-45, which is consistent with the previous 4 analyses.

Object scores labelled by cause of death

The following figures present the objects plotted against the three dimensions and identified by their cause of death.

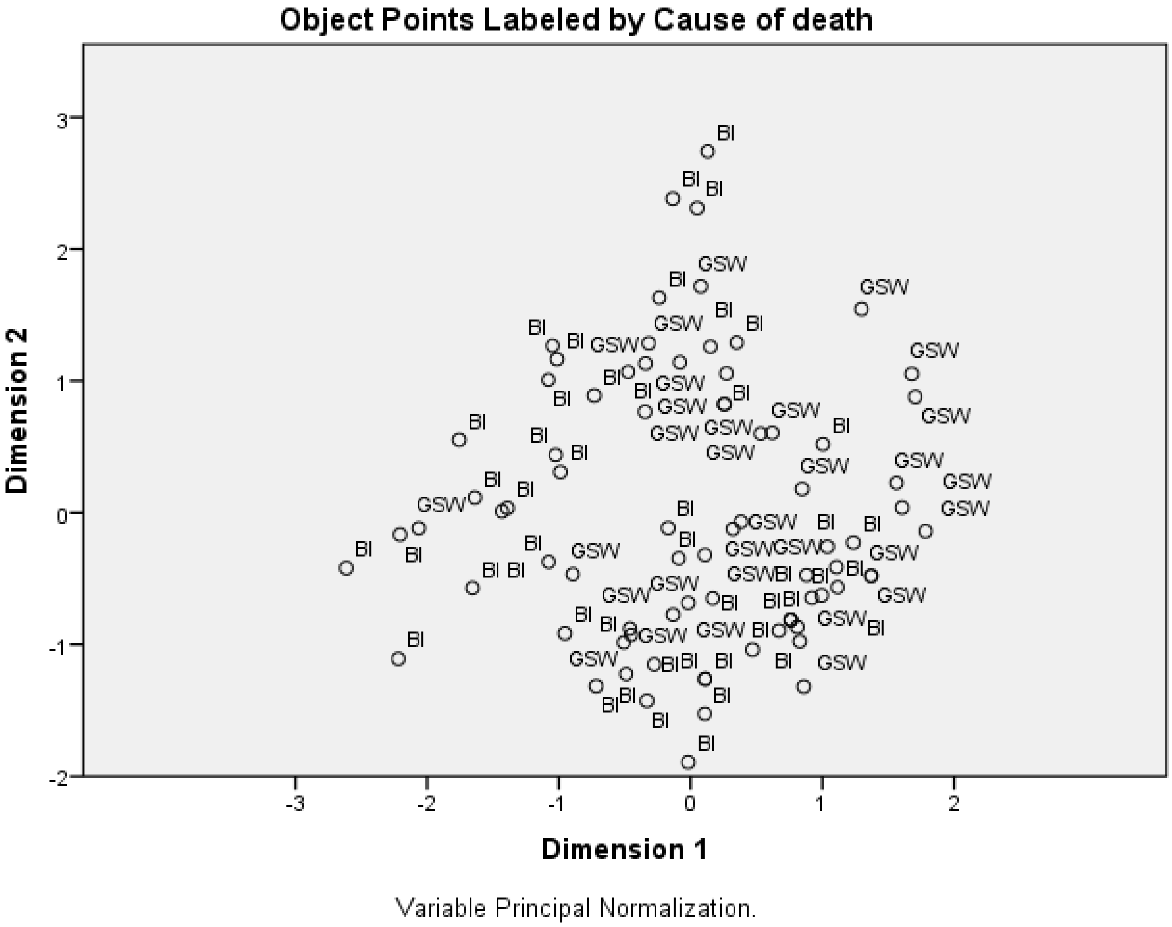

Figure 6-23: Object points labelled by cause of death for dimensions 1 and 2 for analysis #5. No pattern differentiating between the two causes of death is seen on both Dimension 1 and 2.

Across both dimensions 1 and 2, seen in Figure 6-23: Object points labelled by cause of death for dimensions 1 and 2 for analysis #5. No pattern differentiating between the two causes of death is seen on both Dimension 1 and 2.there is no evident pattern or differentiation between the two causes of death.

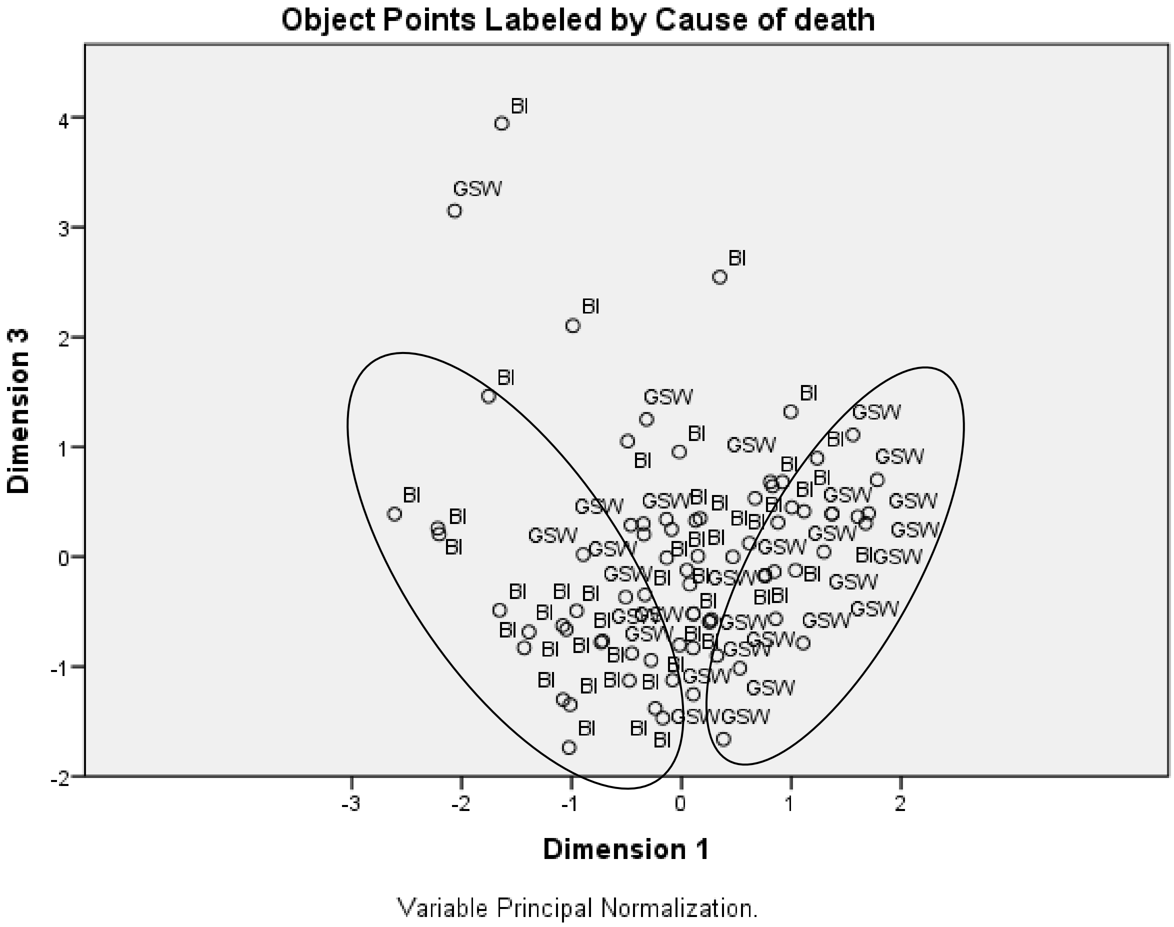

Figure 6-24: Object points labelled by cause of death for dimensions 1 and 3 for analysis #5.

In dimensions 1 and 3, shown in

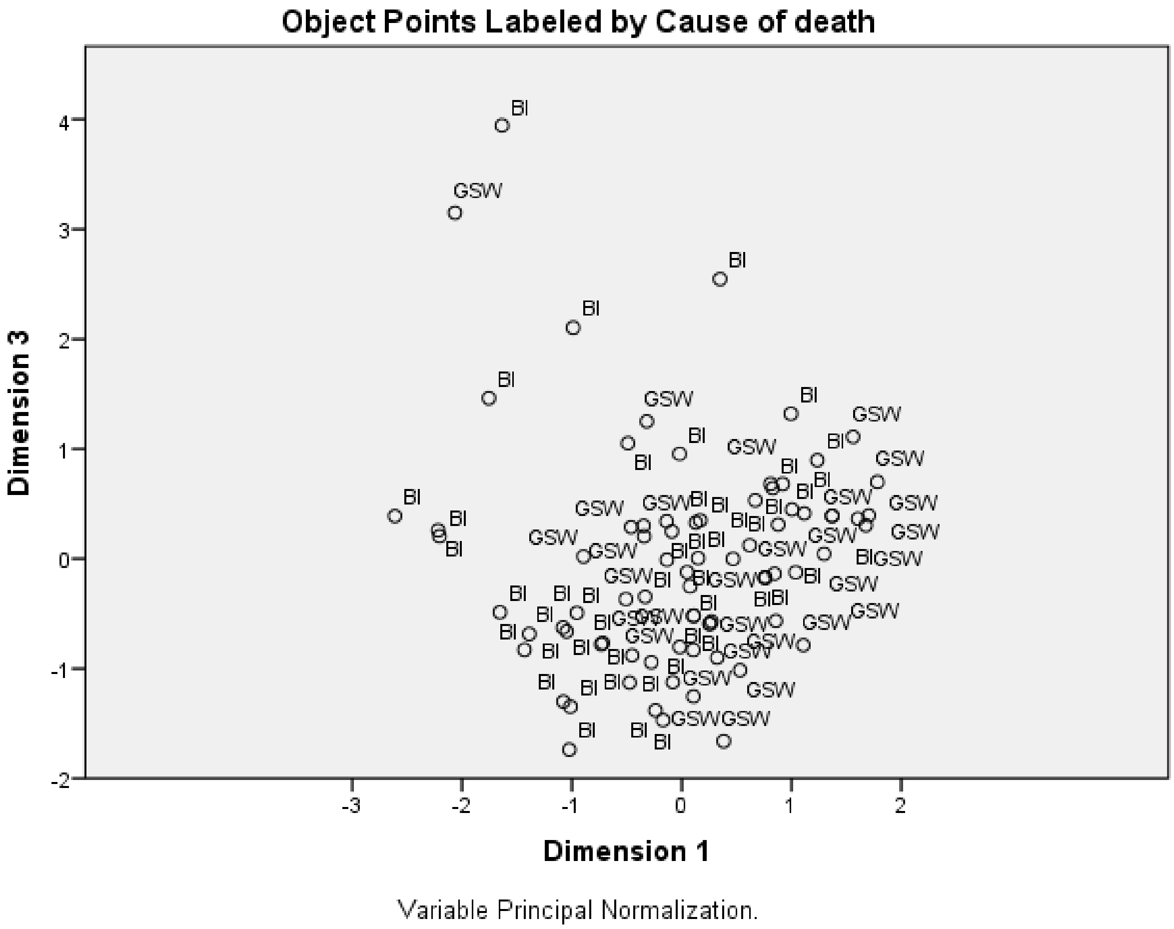

Figure 6-24: Object points labelled by cause of death for dimensions 1 and 3 for analysis #5. differentiation between the causes of death can be seen on dimension 1 with the opposite of previous subsamples happening, with gunshot wound cases on the positive side of the axis and blast injury on the negative side. There is overlap between the two in the middle, but for some cases there is differentiation and clusters of cases belonging to the same cause of death.

Discrimination measures

The following figures and table illustrate the discrimination measures on three dimensions for the sample.

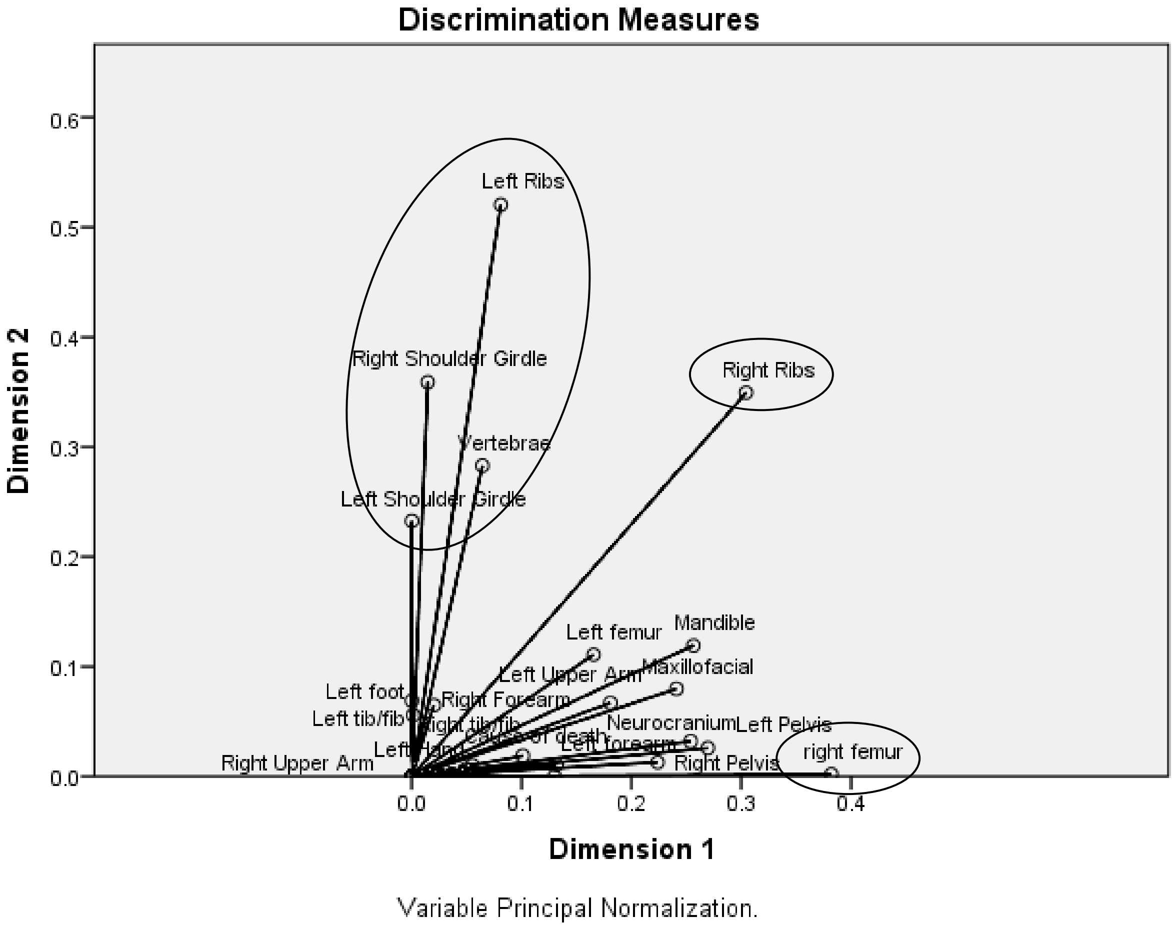

Figure 6-25: Discrimination measures for analysis #5 between dimensions 1 and 2

For dimensions 1 and 2, variables which contribute most to the variance are identified on both axes in Figure 6-25. For dimension 1, the right femur differentiates best on this dimension. For dimension 2, those whose differentiate best (placed furthest from the origin on dimension 2) are the left and right ribs, vertebrae and left and right shoulder girdles. However it was shown that these two dimensions do not differentiate well.

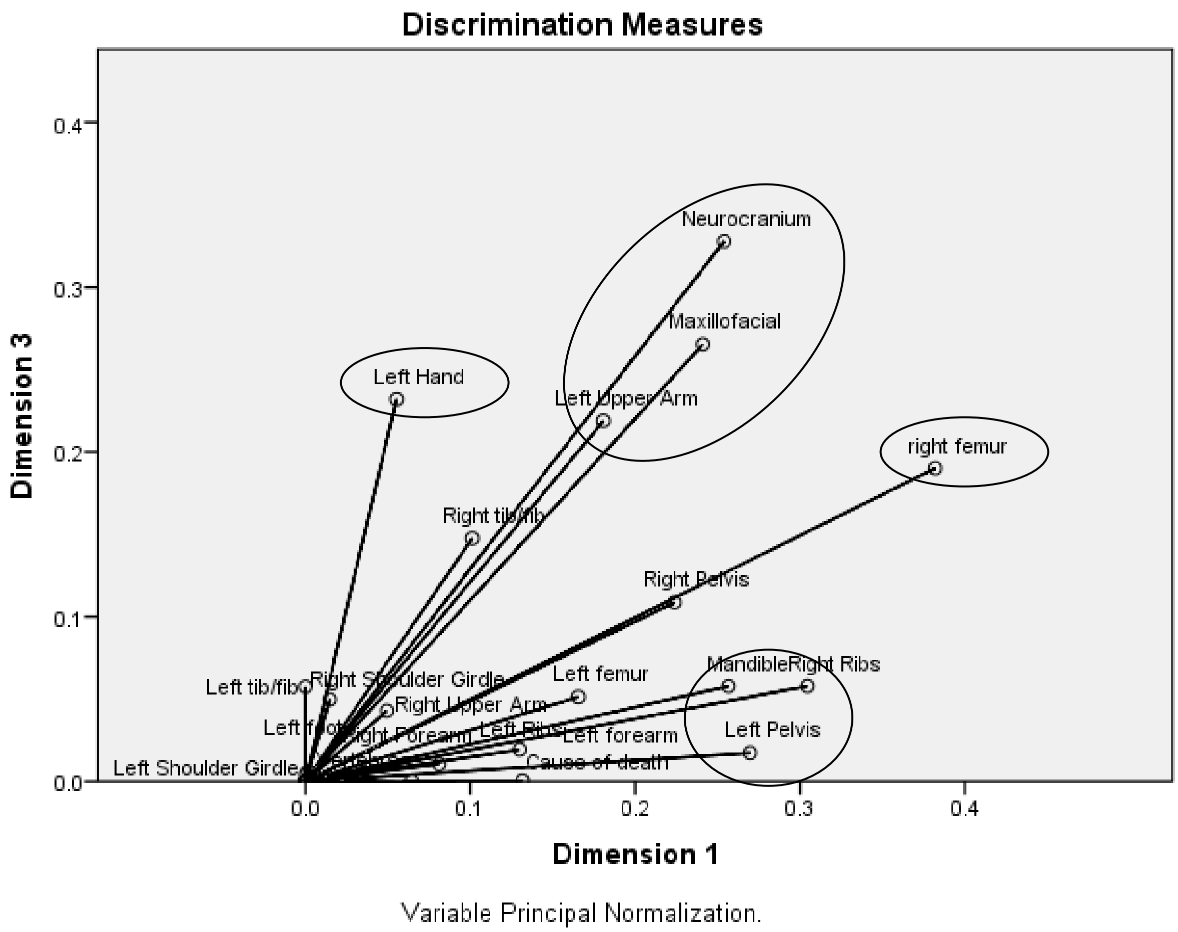

Figure 6-26: Discrimination measures for analysis #5 between dimensions 1 and 3.

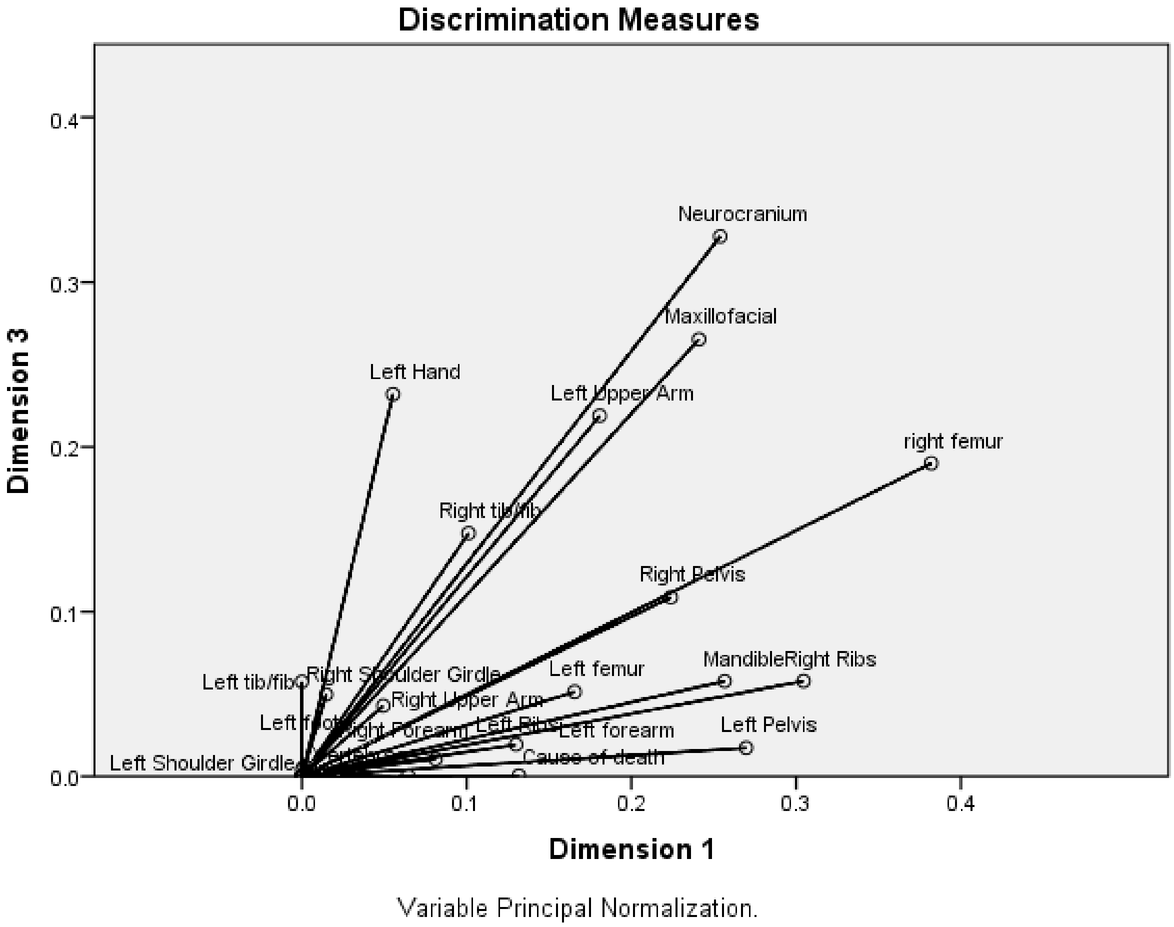

Figure 6-26, there are variables which are distinct from the others on both axes. However, many of these are not specifically discriminating on one particular axis but have high inertia scores for both dimensions. These are circled on the graph above and highlighted in the following table. For dimension 1, the mandible, right ribs, left pelvis and right femur are identified. For dimension 3, the left hand, neurocranium, maxillofacial and left upper arm are identified as the variables which contribute most variance to dimension three (along with some of dimension 1).

Table 6-46 shows the variance contribution for the discrimination measures across the dimensions.

Table 6-46: Discrimination measures for analysis #5. Variables with the largest inertia on Dimension 1 are highlighted in bold.

Discrimination Measures				
	Dimension			
	1	2	3	Mean
Cause of death	.132	.011	.001	.048
Neurocranium	.254	.032	.328	.205
Maxillofacial	.241	.080	.265	.195
Mandible	**.257**	.119	.058	.145
Vertebrae	.064	.283	.000	.116
Left Shoulder Girdle	.000	.233	.004	.079
Right Shoulder Girdle	.015	.359	.050	.141
Left Upper Arm	.181	.067	.219	.156
Right Upper Arm	.049	.006	.043	.033
Left forearm	.130	.000	.019	.050
Right Forearm	.020	.065	.001	.029
Left Hand	.055	.010	.232	.099
Left Ribs	.081	.520	.010	.204
Right Ribs	**.304**	.349	.058	.237
Left Pelvis	**.270**	.026	.017	.104
Right Pelvis	.224	.013	.109	.115
Left femur	.166	.111	.051	.109
Right femur	**.382**	.002	.190	.191
Left tib/fib	.000	.069	.058	.042
Right tib/fib	.101	.019	.148	.089
Left foot	.001	.056	.006	.021
Active Total	2.927	2.429	1.867	2.407
% of Variance	13.939	11.565	8.888	11.464

6.4.6. **Analysis #6**

The final multiple correspondence analysis was performed using 100 cases (N = 52 gunshot wound cases).

Model summary

Table 6-47presents the model summary for analysis #6 detailing the amount of variance accounted for on three dimensions.

Table 6-47: Model summary for analysis #6.

Model Summary				
		Variance Accounted For		
Dimension	Cronbach's Alpha	Total (Eigenvalue)	Inertia	% of Variance
1	.697	2.973	.142	14.157
2	.601	2.340	.111	11.141
3	.509	1.942	.092	9.248
Total		7.255	.345	
Mean	.616[a]	2.418	.115	11.516
a. Mean Cronbach's Alpha is based on the mean Eigenvalue.				

The total variance accounted for with the three dimensions is 34.547%, consistent with the previous analyses using the random subsampling.

Object scores labelled by cause of death

The following figures show the objects labelled by cause of death, plotted on the first and second dimensions and the first and third dimensions.

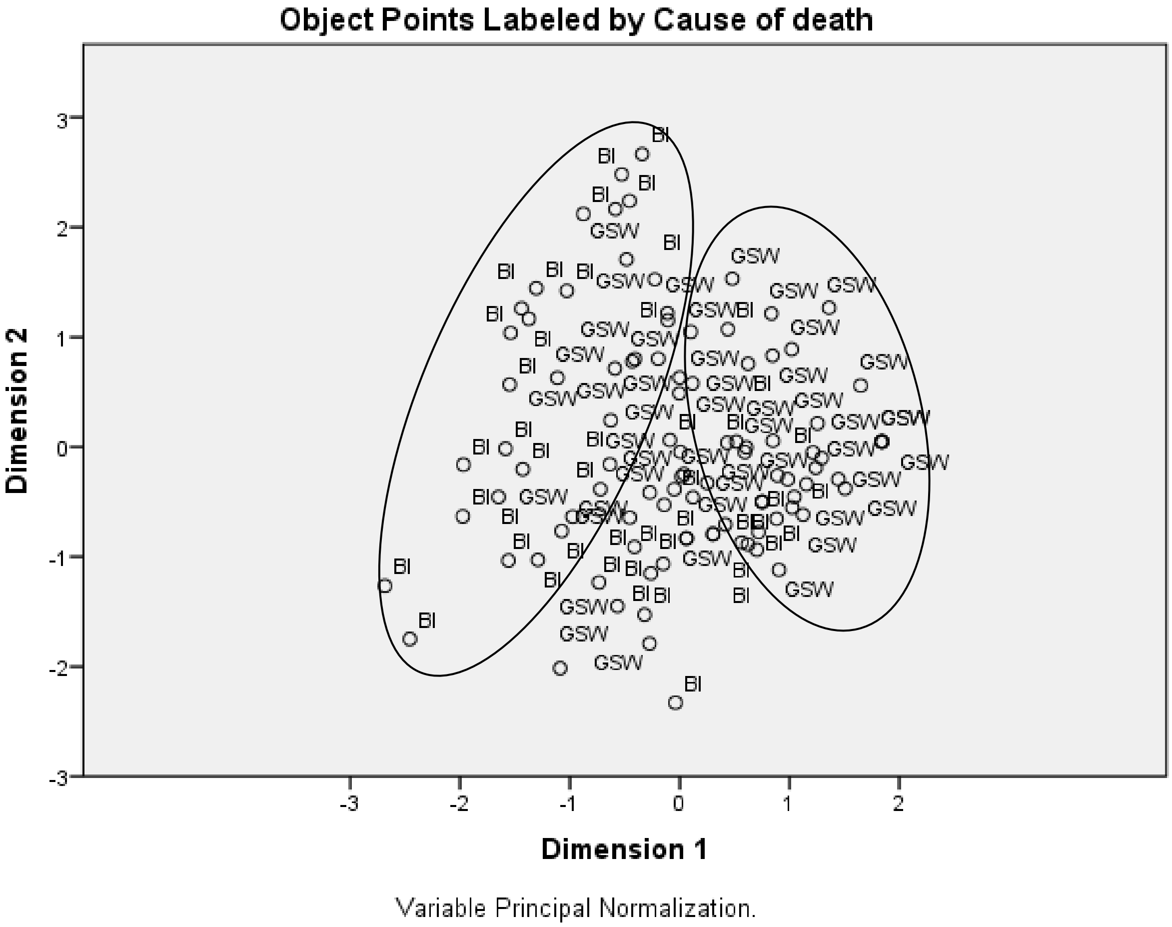

Figure 6-27: Object points labelled by cause of death for dimensions 1 and 2 for analysis #6. Differentiation is shown on Dimension 1 with blast injury cases on the negative side of the axis.

Objects plotted on dimensions 1 and 2 in Figure 6-27show a pattern with the dimension 1 separating the majority of blast injury cases from the gunshot wound death cases, with the blast injury cases on the negative side of the axis. Dimension 2 does not show an apparent graphical differentiation between the two causes of death.

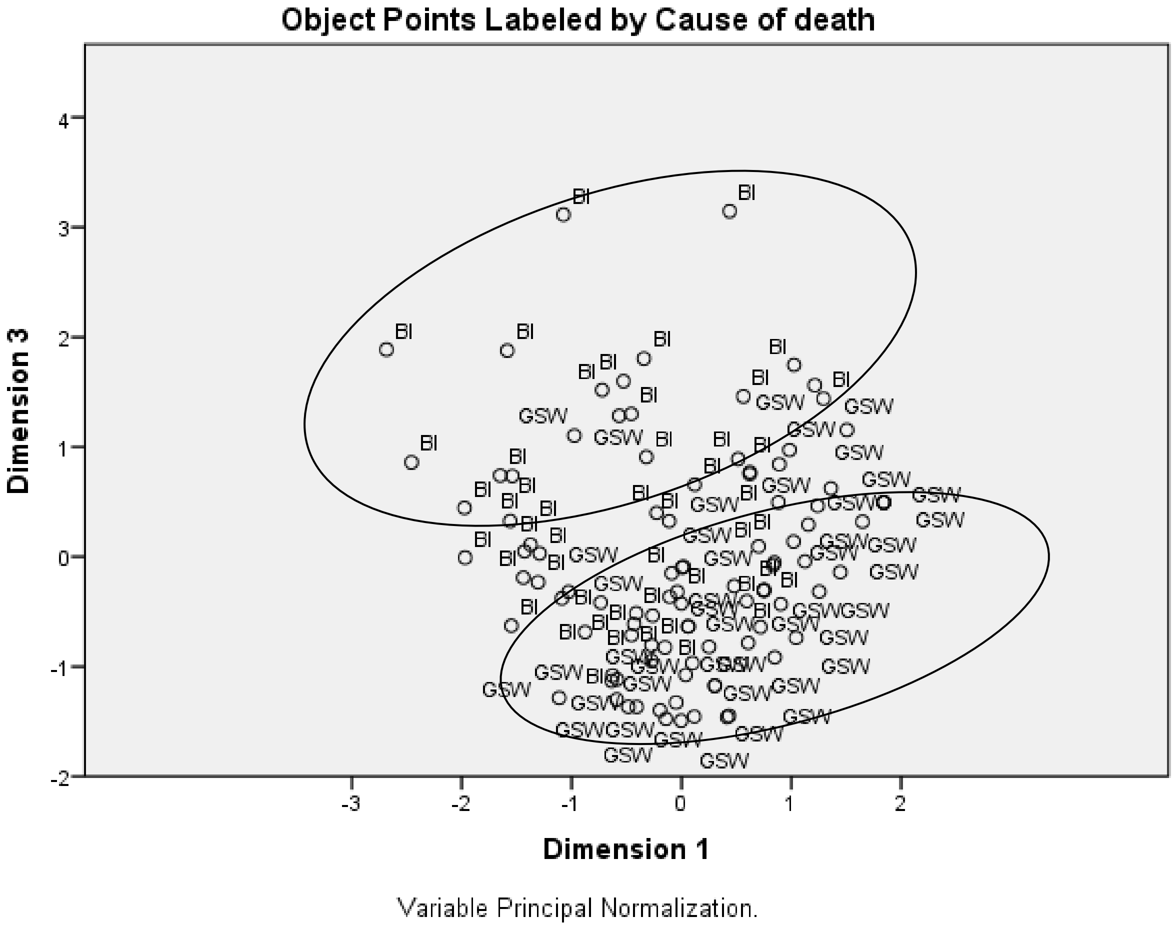

Figure 6-28: Object points labelled by cause of death for dimensions 1 and 3. Dimension 3 discriminates between the two causes of death with blast injury clustering on the positive side of the axis.

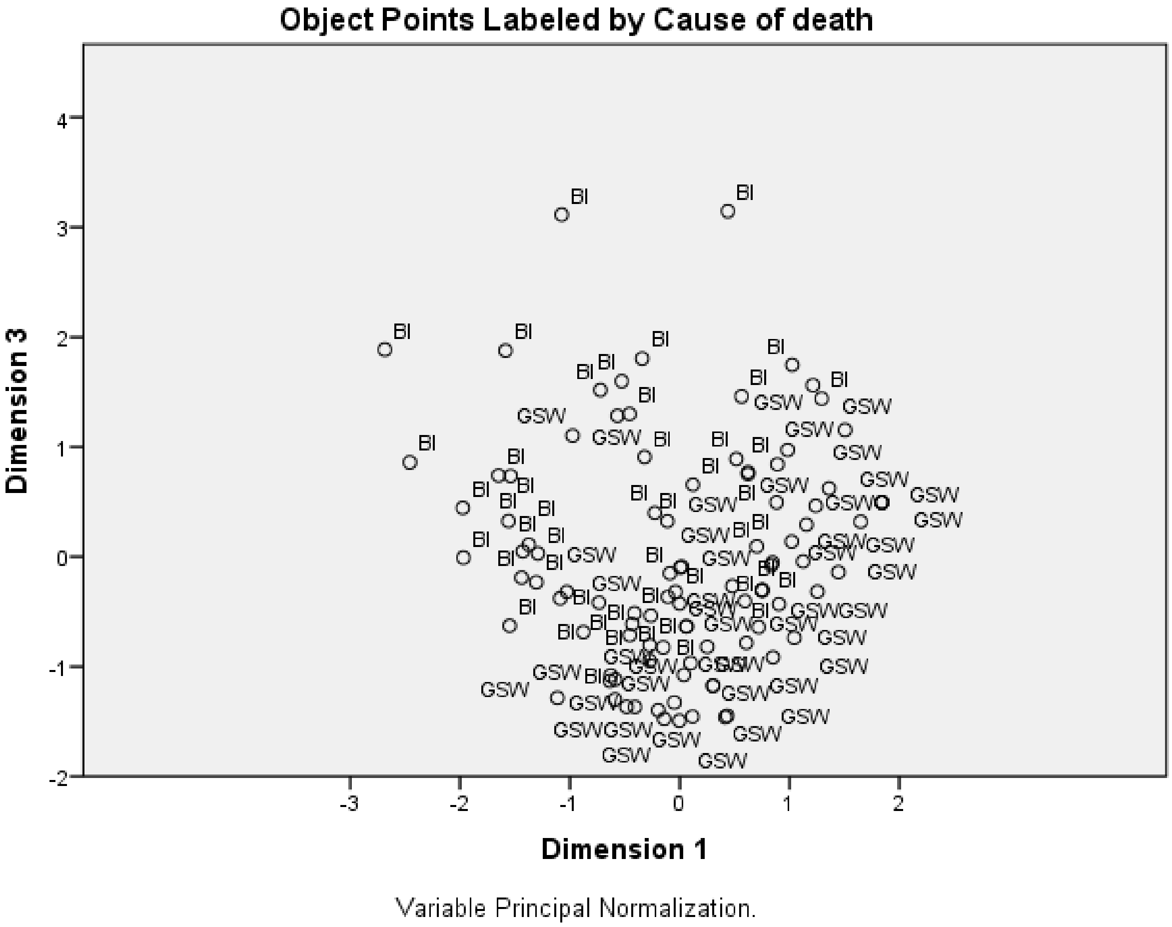

Figure 6-28 representing the objects on dimensions 1 and 3, a pattern can be seen. Over dimension 3, the gunshot wound cases cluster on the negative side of the axis, with the blast injury cases clustered in the positive portion of the axis. Additionally, dimension 1 separates a portion of the gunshot wound cases from the blast injury cases, with gunshot wound cases predominantly on the positive side of the axis.

Discrimination measures

The following results demonstrate the body region variables which contribute most variance to the three dimensions.

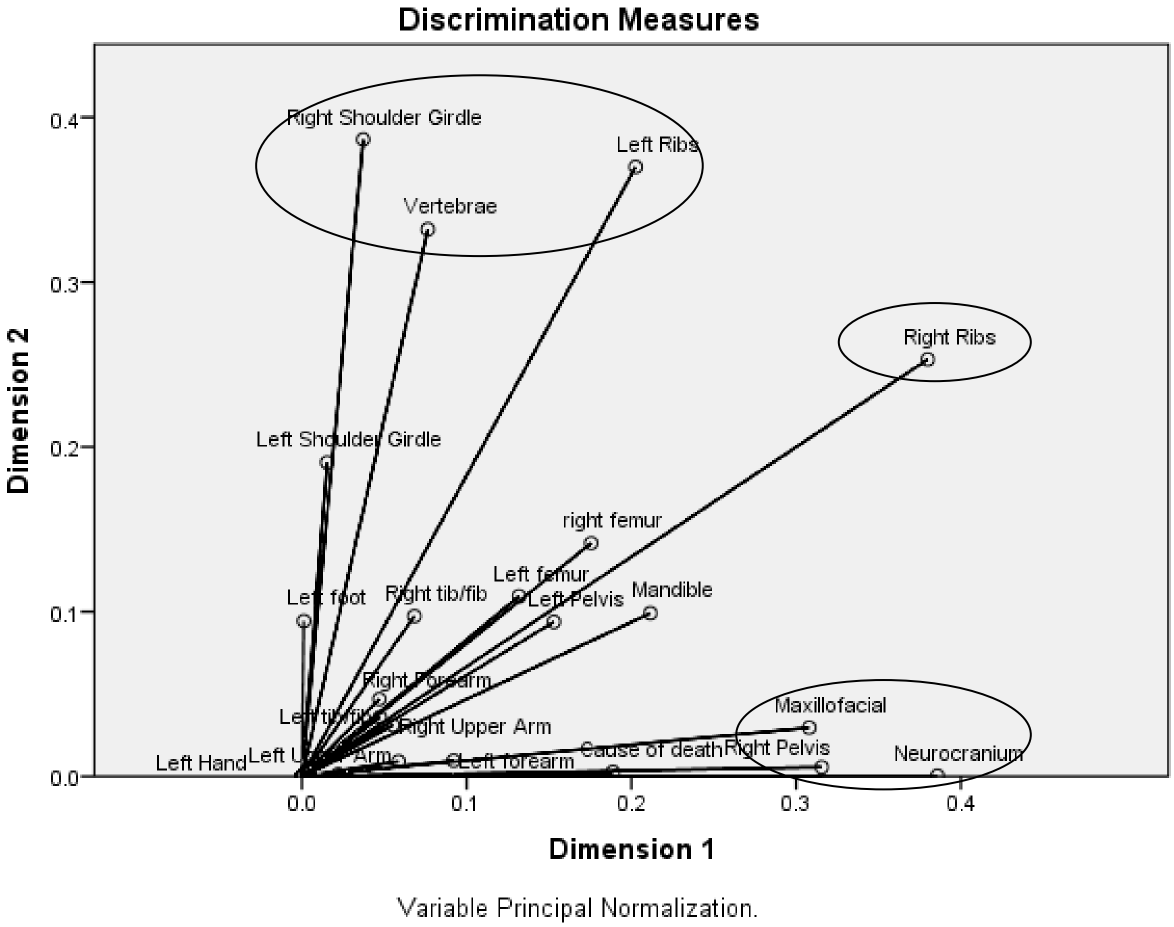

Figure 6-29: Discrimination measures for analysis #6 between dimensions 1 and 2. Variables discriminating on Dimension 1 are neurocranium, maxillofacial and right pelvis. Additionally the right ribs discriminate on Dimension 1 as well as having a large contribution of inertia to Dimension 3.

Dimensions 1 and 2 feature discriminating body region variables on both dimensions, shown in

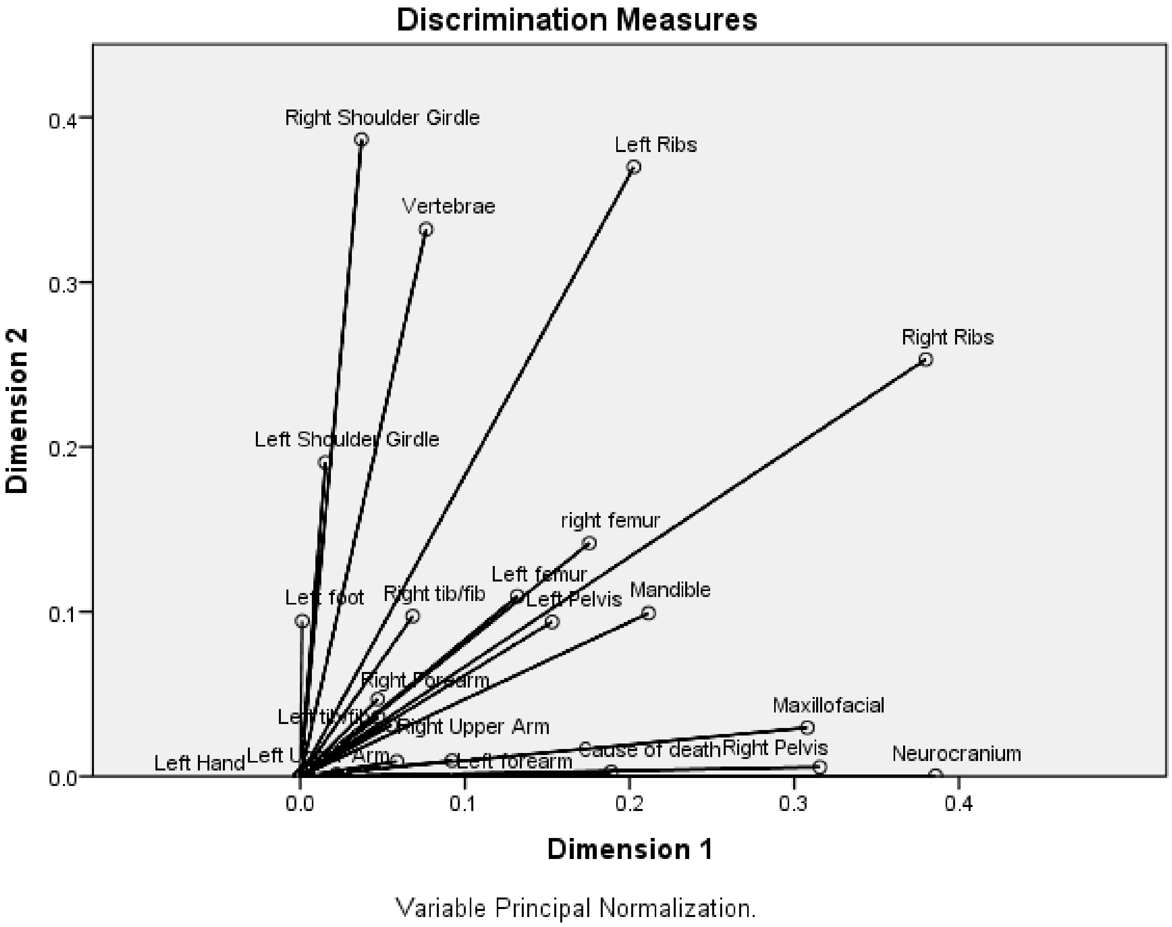

Figure 6-29. For dimension 1, the body region variables maxillofacial, right pelvis and neurocranium discriminate to a high degree between categories. Additionally, the right ribs discriminate on dimension 1 but also contribute to dimension 2. On the second dimension, the right shoulder, vertebrae and left ribs discriminate, however these do not differentiate between the two causes of death on Dimension 2.

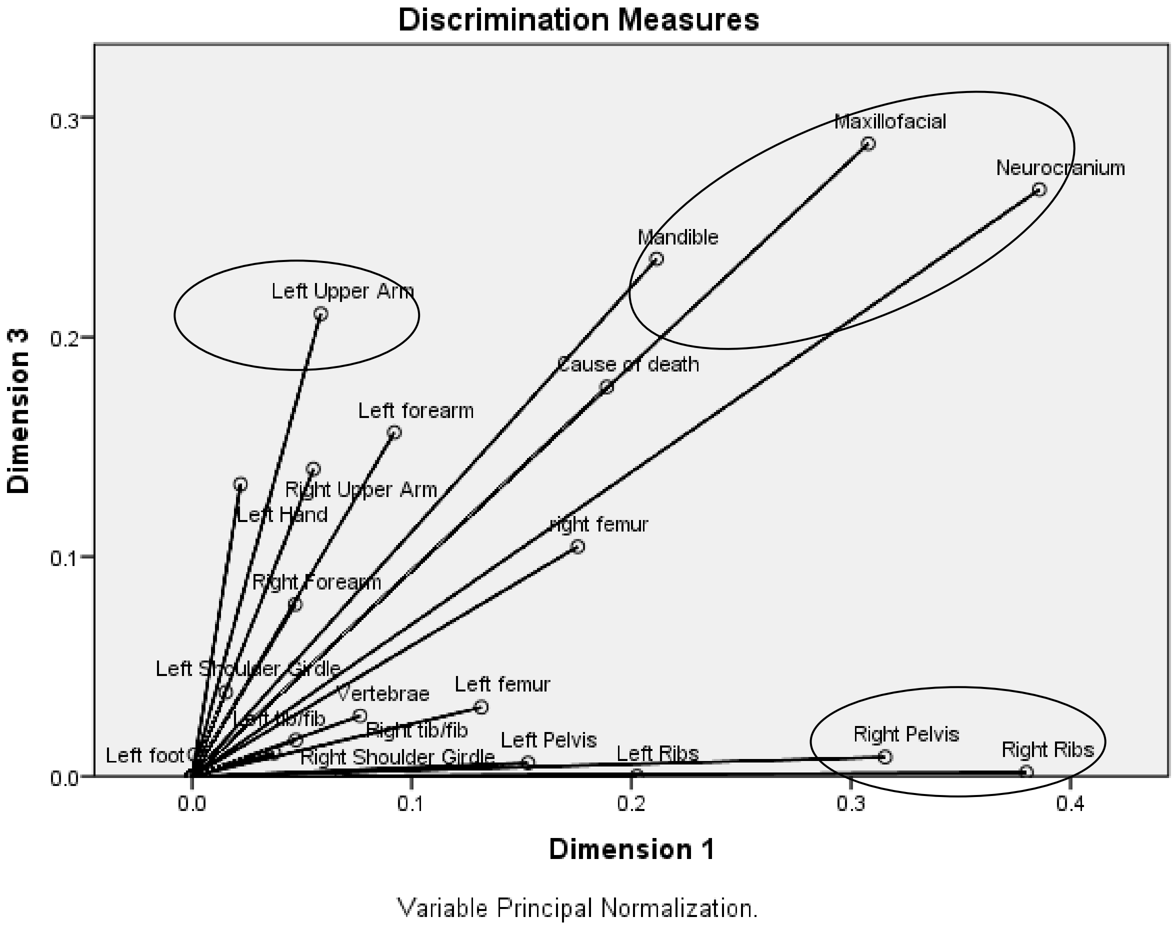

Figure 6-30: Discrimination measures for analysis #6 between dimensions 1 and 3. Variables differentiating on Dimension 1 are the right pelvis and right ribs. On Dimension 3, the left upper arm contributes most to the variance between the groups. The mandible, maxillofacial and neurocranium variables contribute in combination to both Dimensions 1 and 3.

For dimensions 1 and 3, discriminating variables can be identified, illustrated in Figure 6-30. On dimension 1, the right pelvis and right ribs discriminate highly between categories. Additionally, three variables discriminate well between categories on a combination of the first and third dimensions. These are the mandible, maxillofacial and neurocranium body region variables. On the third dimension, the variables do not discriminate as well, but the left upper arm discriminates with a high inertia value on the second dimension and a small one on the first dimension.

The discriminating measures and their variance contributions to the three dimensions are shown in Table 6-48.

Table 6-48: Discrimination measures for analysis #6. Discriminating variables for Dimensions 1 and 3 are highlighted in bold.

Discrimination Measures				
	Dimension			Mean
	1	2	3	
Cause of death	.189	.003	.177	.123
Neurocranium	**.386**	.000	**.267**	.218
Maxillofacial	**.308**	.030	**.288**	.209
Mandible	**.211**	.099	**.236**	.182
Vertebrae	.077	.332	.028	.145
Left Shoulder Girdle	.015	.191	.038	.081
Right Shoulder Girdle	.037	.387	.011	.145
Left Upper Arm	.059	.009	**.211**	.093
Right Upper Arm	.055	.031	.140	.075
Left forearm	.092	.010	.157	.086
Right Forearm	.047	.047	.078	.057
Left Hand	.022	.001	.133	.052
Left Ribs	.203	.370	.000	.191
Right Ribs	**.380**	.253	.002	.212
Left Pelvis	.153	.094	.006	.084
Right Pelvis	**.315**	.006	.009	.110
Left femur	.132	.109	.031	.091
right femur	.176	.142	.105	.141
Left tib/fib	.047	.036	.017	.033
Right tib/fib	.068	.097	.000	.055
Left foot	.001	.094	.010	.035
Active Total	2.973	2.340	1.942	2.418
% of Variance	14.157	11.141	9.248	11.516

6.4.7. Summary of multiple correspondence analysis

Using multiple correspondence analysis, body region variables which discriminate well have been identified. The following variables were:

Table 6-49: Summary of body region variables identified in multiple correspondence analysis. Number in parentheses represent the times which each variable is identified as an important discrimination measure in the analysis.

Dimension 1	**Dimension 2**	**Dimension 3**
Neurocranium (3)	Mandible (2)	Neurocranium (5)
Right ribs (6)	Vertebrae (3)	Maxillofacial (5)
Left pelvis (3)	Left shoulder girdle (3)	Right femur (1)
Right pelvis (2)	Right shoulder girdle (4)	Right tibia and fibula (2)
Right femur	Left ribs (5)	Left forearm (2)
Left upper arm (1)	Maxillofacial (1)	Left upper arm (3)
Left ribs (1)	Neurocranium (1)	Left hand (2)
Maxillofacial (2)	Right ribs (1)	Mandible (1)
Mandible (2)		

Certain variables are consistently identified in the analysis as differentiating between the categories and will be tested subsequently as predictor variables of the cause of death in the binary logistic regression in the next section. These variables are those which appear most frequently for dimension 1 and dimension 2 and which account for the most variance in the model. The variables selected were: neurocranium, mandible, left and right shoulder girdles, left upper arm, left ribs, left pelvis, right pelvis, right femur, left femur, maxillofacial and vertebrae.

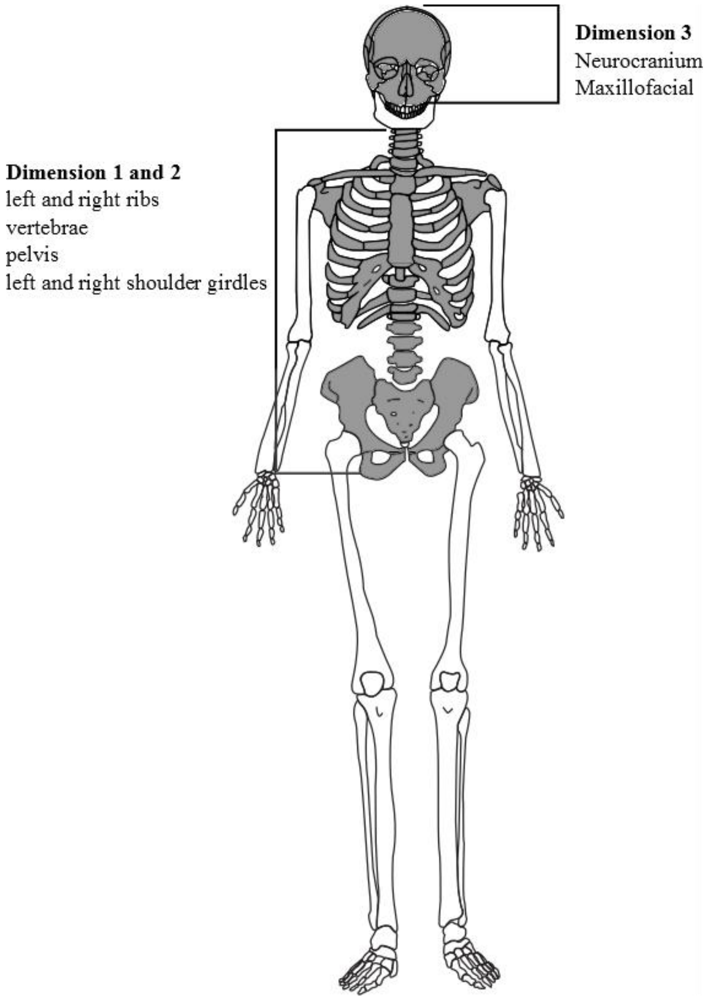

Figure 6-31: Body regions represented by the dimensions in the multiple correspondence analysis of the Bosnia samples, differentiating blast injury from gunshot wounds.

The three dimensions accounting for the most variance between the samples represent a pattern showing the differences between the trauma in blast injury and gunshot wounds. The variables differentiating on dimensions 1 and 2 represent the trunk region of the body, such as ribs, vertebrae, pelvic area and shoulder girdles. Dimension 3 predominantly represents the cranial area with the neurocranium and maxillofacial variables being of importance in differentiating between the two causes of death. The dimensions which differentiate most between the two causes of death are dimension 1 and 3, representing the torso area and the cranial area. The dimensions are represented in Figure 6-31: Body regions represented by the dimensions in the multiple correspondence analysis of the Bosnia samples, differentiating blast injury from gunshot wounds.

6.5. Binary logistic regression

The following section presents the results of the binary logistic regression phase of the analysis. The first part presents the results of a backwards logistic regression which is run automatically by SPSS that selects variables with the criteria cut-offs specified in the syntax (section 5.5.4). This is also compared to a block enter method (where all variables are pre-selected and entered at once) using the variables identified in the multiple correspondence analysis in Section 6.4: Multiple correspondence analysis.

6.5.1. Backwards binary logistic regression

The first binary logistic regression undertaken employed the backwards stepwise logistic regression based on a likelihood ratio criteria for inclusion/exclusion of the variables. The analysis was undertaken multiple times, with a subsampling command in the syntax file to ascertain the selection of a similar number of cases from each cause of death. The number of cases per cause of death will be noted with the results.

Analysis #1

This was undertaken with a total of 87 cases (48 cases of blast injury and 39 cases of gunshot wound cause of death).

Table 6-50: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #1.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
17	.421	2	.810

Through 17 steps, the significance of the Hosmer and Lemeshow's test varies. By step 17, shown in Table 6-50 , the significance is 0.810 which indicates a good fit of the model (the closer the significance is to the value 1, the better the fit of the model with $p \leq 0.05$ being a poorly fitting model).

Table 6-51: Statistics for variables included in the model using backward stepwise method.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 17[a]	LForearm(1)	2.055	.690	8.883	1	.003	7.810	2.021	30.177
	LFemur(1)	1.153	.523	4.851	1	.028	3.167	1.135	8.834
	Constant	-2.679	.782	11.727	1	.001	.069		
a. Variable(s) entered on step 1: Neurocranium, Maxillofacial, Mandible, Vertebrae, LShoulder, RShoulder, LUpArm, RUpArm, LForearm, RForearm, LRibs, RRibs, LPelvis, RPelvis, LFemur, RFemur, LTibFib, RTibFib.									

The variables selected by SPSS using the backward stepwise method indicate that the left forearm and femurs are best predictors, summarised in Table 6-51.

Table 6-52: Classification table using left forearm and left femur as indicators.

Classification Table[a]					
			Predicted		
			Cause of death		Percentage Correct
	Observed		BI	GSW	
Step 17	Cause of death	BI	31	17	64.6
		GSW	11	28	71.8
	Overall Percentage				67.8

Using the left forearm and femur predictors, 67.8% of cases are predicted accurately, shown in Table 6-52. This is an increase of 12.6% from the basic model including the constant only.

Analysis #2

The second iteration of the analysis was undertaken with 94 cases (N= 46 gunshot wound deaths).

Table 6-53: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #2.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
13	5.118	6	.529

The Hosmer and Lemeshow's test indicates a model fit which is adequate, shown in Table 6-53.

Table 6-54: Statistics for variables included in the model using backward stepwise method.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 13[a]	Vertebrae(1)	-1.194	.608	3.854	1	.050	.303	.092	.998
	RShoulder(1)	2.021	.789	6.558	1	.010	7.542	1.607	35.406
	RUpArm(1)	2.602	1.650	2.487	1	.115	13.492	.532	342.333
	LForearm(1)	3.949	1.205	10.736	1	.001	51.886	4.888	550.749
	RForearm(1)	-2.301	1.379	2.783	1	.095	.100	.007	1.495
	LFemur(1)	1.210	.567	4.550	1	.033	3.354	1.103	10.199
	Constant	-5.595	1.740	10.344	1	.001	.004		
a. Variable(s) entered on step 1: Neurocranium, Maxillofacial, Mandible, Vertebrae, LShoulder, RShoulder, LUpArm, RUpArm, LForearm, RForearm, LRibs, RRibs, LPelvis, RPelvis, LFemur, RFemur, LTibFib, RTibFib.									

The variables selected by the backward stepwise method are the vertebrae, right shoulder, right upper arm, left upper arm, right forearm and left femur, shown in Table 6-54.

Table 6-55: Classification table using vertebrae, right shoulder girdle, right upper arm, left forearm, right forearm and left femur.

Classification Table[a]					
			Predicted		
			Cause of death		Percentage Correct
	Observed		BI	GSW	
Step 13	Cause of death	BI	38	10	79.2
		GSW	9	37	80.4
	Overall Percentage				79.8
a. The cut value is .500					

Using the variables selected the percentage of classification is 79.8%, an increase of 28.7% in correct predictions, shown in Table 6-55.

Table 6-56: Outliers identified in analysis #2.

Casewise List[b]							
			Observed			Temporary Variable	
Case	Case ID	Selected Status[a]	Cause of death	Predicted	Predicted Group	Resid	ZResid
17	GL01/460	S	B**	.868	G	-.868	-2.568
58	GL01/620	S	G**	.037	B	.963	5.096
a. S = Selected, U = Unselected cases, and ** = Misclassified cases. b. Cases with studentized residuals greater than 2.000 are listed.							

Two cases were identified as outliers (see Table 6-56: Outliers identified in analysis #2.), having been predicted as belonging to the wrong group and having high standardized residuals.

Analysis #3

The follow analysis was undertaken with 95 cases (N= 47 gunshot wound deaths).

Table 6-57: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #3.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
16	.555	3	.907

16 steps were performed by SPSS to identify the indicator variables. The Hosmer and Lemeshow's statistic in Table 6-57 indicates a very good fit of the model.

Table 6-58: Statistics for variables included in the model using backward stepwise method.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 16[a]	RShoulder(1)	1.277	.581	4.836	1	.028	3.587	1.149	11.199
	LForearm(1)	2.265	.667	11.521	1	.001	9.635	2.605	35.641
	LFemur(1)	2.495	.663	14.143	1	.000	12.118	3.302	44.469
	Constant	-4.746	1.099	18.657	1	.000	.009		
a. Variable(s) entered on step 1: Neurocranium, Maxillofacial, Mandible, Vertebrae, LShoulder, RShoulder, LUpArm, RUpArm, LForearm, RForearm, LRibs, RRibs, LPelvis, RPelvis, LFemur, RFemur, LTibFib, RTibFib.									

The model produced shows in Table 6-58 that the following variables to predict the outcome of the cause of death variable: right shoulder girdle, left forearm, and left femur.

Table 6-59: Classification table using right shoulder girdle, left forearm and left femur variables.

Classification Table[a]					
			Predicted		
			Cause of death		Percentage Correct
	Observed		BI	GSW	
Step 16	Cause of death	BI	31	17	64.6
		GSW	8	39	83.0
	Overall Percentage				73.7
a. The cut value is .500					

The classification of cases using the predictor variables increases the percentage correct from 50.5% to 73.7%, an increase of 23.2%, shown in Table 6-59.

Table 6-60: Outliers identified in analysis #3.

Casewise List[b]							
			Observed			Temporary Variable	
Case	Case ID	Selected Status[a]	Cause of death	Predicted	Predicted Group	Resid	ZResid
63	RV02/014	S	G**	.095	B	.905	3.082
a. S = Selected, U = Unselected cases, and ** = Misclassified cases. b. Cases with studentized residuals greater than 2.000 are listed.							

The analysis identified one outlier case, seen in Table 6-60, which was misclassified in the blast injury group and a studentized residual of 3.082.

Analysis #4

The fourth analysis was undertaken using a subsample of 84 cases (N= 36 gunshot wound cause of death cases).

Table 6-61: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #4.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
17	.153	5	1.000

At step 17, the statistic shows a significance of 1.000 in Table 6-61, indicating a model which perfectly predicts outcome of the cause of death dependent variable.

Table 6-62: Statistics for variables included in the model using backward stepwise method for analysis #4.

Variables in the Equation								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp (B)	Lower	Upper
Step 17[b]	Vertebrae(1)	-1.537	.633	5.901	1	.015	.215	.062	.743
	RShoulder(1)	1.752	.722	5.890	1	.015	5.768	1.401	23.749
	LForearm(1)	3.013	.903	11.131	1	.001	20.344	3.466	119.426
	LFemur(1)	1.118	.571	3.829	1	.050	3.058	.998	9.370
	Constant	-4.018	1.149	12.225	1	.000	.018		

a. Variable(s) entered on step 1: Neurocranium, Maxillofacial, Mandible, Vertebrae, LShoulder, RShoulder, LUpArm, RUpArm, LForearm, RForearm, LRibs, RRibs, LPelvis, RPelvis, LFemur, RFemur, LTibFib, RTibFib.
b. Variable(s) entered on step 17: LFemur.

Table 6-62 indicates that the variables selected for the model are: vertebrae, right shoulder girdle, left forearm and left femur.

Table 6-63: Classification table using the predictor variables vertebrae, right shoulder girdle, left forearm and left femur for analysis #4.

Classification Table[a]					
			Predicted		
			Cause of death		Percentage Correct
	Observed		BI	GSW	
Step 17	Cause of death	BI	32	16	66.7
		GSW	8	28	77.8
	Overall Percentage				71.4

Using the predictor variables vertebrae, right shoulder girdle, left forearm and left femur, the classification percentage is 71.4%, an increase of 14.3%, shown in Table 6-63.

Table 6-64: outliers identified in analysis #4.

Casewise List[b]							
			Observed			Temporary Variable	
Case	Case ID	Selected Status[a]	Cause of death	Predicted	Predicted Group	Resid	ZResid
17	GL01/460	S	B**	.866	G	-.866	-2.542
66	RV02/204	S	G**	.094	B	.906	3.104

a. S = Selected, U = Unselected cases, and ** = Misclassified cases.
b. Cases with studentized residuals greater than 2.000 are listed.

The analysis identified two outlier cases, seen in Table 6-64, which were incorrectly attributed to the wrong groups. One case of blast injury was classified as gunshot wound, with a studentized residual of -2.542. The second case was classified as blast injury rather than gunshot wound cause of death, with a studentized residual of 3.104.

Analysis #5

The final analysis using the backward stepwise method of binary logistic regression was undertaken with 103 cases in the random subsample (N=55 gunshot wound cases).

Table 6-65: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #5.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
13	4.889	6	.558

At the end of the analysis after 13 steps, the Hosmer and Lemeshow's statistic has a significance of 0.558, which indicates a good model fit ($p \geq 0.05$). This is shown in Table 6-65.

Table 6-66: Statistics for variables included in the model using backward stepwise method for analysis #5.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp (B)	Lower	Upper
Step 13[a]	RUpArm (1)	3.113	1.387	5.039	1	.025	22.484	1.484	340.558
	LForearm(1)	4.111	1.176	12.215	1	.000	60.985	6.083	611.438
	RForearm(1)	-1.879	1.046	3.228	1	.072	.153	.020	1.186
	LFemur(1)	2.414	.687	12.334	1	.000	11.182	2.906	43.022
	RFemur(1)	-1.565	.760	4.244	1	.039	.209	.047	.927
	LTibFib(1)	1.570	.912	2.964	1	.085	4.809	.805	28.738
	Constant	-6.689	1.963	11.609	1	.001	.001		
a. Variable(s) entered on step 1: Neurocranium, Maxillofacial, Mandible, Vertebrae, LShoulder, RShoulder, LUpArm, RUpArm, LForearm, RForearm, LRibs, RRibs, LPelvis, RPelvis, LFemur, RFemur, LTibFib, RTibFib.									

The indicator variables selected for the optimal model shown in Table 6-66: right upper arm, left forearm, right forearm, left femur, right femur and left tibia and fibula.

Table 6-67: Classification table using predictor variables right upper arm, left forearm, right forearm, left femur, right femur and left tibia and fibula for analysis #5.

Classification Table[a]					
			Predicted		
			Cause of death		Percentage Correct
	Observed		BI	GSW	
Step 13	Cause of death	BI	34	14	70.8
		GSW	5	50	90.9
	Overall Percentage				81.6
a. The cut value is .500					

Using the predictor variables selected in step 13 of the model, the overall prediction percentage was 81.6%. This is an increase of 28.2% in the prediction accuracy of the model using the selected predictor variables. This is shown in Table 6-67.

Table 6-68: outliers identified in analysis #5.

Casewise List[b]							
			Observed			Temporary Variable	
Case	Case ID	Selected Status[a]	Cause of death	Predicted	Predicted Group	Resid	ZResid
81	RV02/301	S	G**	.115	B	.885	2.770
92	LZ2-74	S	G**	.046	B	.954	4.562
a. S = Selected, U = Unselected cases, and ** = Misclassified cases. b. Cases with studentized residuals greater than 2.000 are listed.							

The analysis identified two outlier cases which were misclassified, shown in Table 6-68. The two cases were identified as having a cause of death being gunshot wound. The model classified them as blast injury cause of death, with studentized residuals of 2.770 and 4.562.

6.5.2. **Block enter binary logistic regression**

The second portion of the binary logistic regression was undertaken using the body region variables identified in the multiple correspondence analysis previously accomplished. The results from these will be outlined for 5 analyses undertaken with the subsample created by the syntax. Testing of the assumptions of the final models produced will also be undertaken to assess the suitability of the model.

Analysis #1

The analysis was undertaken using 88 cases (N=40 gunshot wound cases). The following results include the Hosmer and Lemeshow's goodness-of-fit statistic, the individual statistics for the body region variables in the model, the classification table and the multicollinearity assessment.

Table 6-69: Hosmer and Lemeshow's Goodness-of-Fit for analysis #1.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	6.032	8	.644

The Hosmer and Lemeshow's statistic had a significance of 0.644, presented in Table 6-69, which surpasses the criteria required to indicate a good model fit ($p \geq 0.05$).

Table 6-70: Statistics for variables included in the model using the block enter method for analysis #1.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Neurocranium(1)	.060	.616	.010	1	.922	1.062	.317	3.553
	Mandible(1)	-1.005	.829	1.470	1	.225	.366	.072	1.859
	LShoulder(1)	-.430	.753	.325	1	.568	.651	.149	2.848
	RShoulder(1)	.479	.608	.619	1	.431	1.614	.490	5.317
	LUpArm(1)	-1.078	.825	1.708	1	.191	.340	.068	1.714
	LRibs(1)	.464	.693	.448	1	.504	1.590	.409	6.184
	RRibs(1)	-.804	.726	1.225	1	.268	.448	.108	1.858
	LPelvis(1)	.108	.685	.025	1	.875	1.114	.291	4.268
	RPelvis(1)	-1.393	.689	4.086	1	.043	.248	.064	.958
	RFemur(1)	1.475	.745	3.923	1	.048	4.370	1.015	18.808
	LFemur(1)	-2.068	.715	8.364	1	.004	.126	.031	.513
	Maxillofacial(1)	.471	.684	.476	1	.490	1.602	.420	6.117
	Vertebrae(1)	.548	.593	.855	1	.355	1.730	.541	5.528
	Constant	2.859	1.280	4.987	1	.026	17.449		
a. Variable(s) entered on step 1: Neurocranium, Mandible, LShoulder, RShoulder, LUpArm, LRibs, RRibs, LPelvis, RPelvis, RFemur, LFemur, Maxillofacial, Vertebrae.									

Table 6-70 outlines the test statistic for each of the body region variables included in the model. This includes the Exp(B) statistic which can be used to interpret the change in the odds of the event when increasing from one unit to the other in the predictor. These will be interpreted in the discussion.

Table 6-71: Classification table using predictor variables Neurocranium, Mandible, left shoulder, right shoulder, left upper arm, left ribs, right ribs, left pelvis, right pelvis, right femur, left femur, Maxillofacial, and Vertebrae for analysis #1.

Classification Table[a]					
	Observed		Predicted		
			Cause of death		Percentage Correct
			GSW	BI	
Step 1	Cause of death	GSW	28	12	70.0
		BI	13	35	72.9
	Overall Percentage				71.6
a. The cut value is .500					

Table 6-71 shows the percentage of classification which were correct for this model. The achieved percentage is 71.6%

Analysis #2

The second run of the binary logistic regression was undertaken with 96 cases (N= 48 gunshot wound cases).

Table 6-72: Hosmer and Lemeshow's Goodness-of-Fit for analysis #2.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	13.529	8	.095

Analysing this sample produces a low Hosmer and Lemeshow's significance of 0.095, which is still above the $p \leq 0.05$ cut-off point, indicating a suitable fit of the model. This result is shown in Table 6-72

Table 6-73: Statistics for variables included in the model using the block enter method for analysis #2.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Neurocranium(1)	-1.299	.733	3.137	1	.077	.273	.065	1.149
	Mandible(1)	-.170	.756	.050	1	.823	.844	.192	3.716
	LShoulder(1)	-.043	.613	.005	1	.943	.957	.288	3.184
	RShoulder(1)	-.700	.674	1.078	1	.299	.497	.132	1.862
	LUpArm(1)	-.529	.746	.502	1	.479	.589	.137	2.545
	LRibs(1)	.130	.689	.035	1	.851	1.138	.295	4.396
	RRibs(1)	-.828	.620	1.785	1	.182	.437	.130	1.472
	LPelvis(1)	-.132	.603	.048	1	.827	.877	.269	2.859
	RPelvis(1)	-.702	.605	1.345	1	.246	.496	.151	1.623
	RFemur(1)	.962	.692	1.933	1	.164	2.617	.674	10.159
	LFemur(1)	-1.709	.584	8.545	1	.003	.181	.058	.570
	Maxillofacial(1)	1.138	.750	2.301	1	.129	3.120	.717	13.568
	Vertebrae(1)	.260	.571	.207	1	.649	1.296	.423	3.972
	Constant	2.496	1.162	4.615	1	.032	12.132		

a. Variable(s) entered on step 1: Neurocranium, Mandible, LShoulder, RShoulder, LUpArm, LRibs, RRibs, LPelvis, RPelvis, RFemur, LFemur, Maxillofacial, Vertebrae.

Table 6-73 outlines the test statistic for each of the body region variables included in the model. This includes the Exp(B) statistic which can be used to interpret the change in the odds of the event when increasing from one unit to the other in the predictor. These will be interpreted in the discussion.

Table 6-74: Classification table for body region variables neurocranium, mandible, left and right shoulder girdles, left upper arm, left and right ribs, left and right femur, left and right pelvis, maxillofacial and vertebrae for analysis #2.

Classification Table[a]					
	Observed		Predicted		
			Cause of death		Percentage Correct
			GSW	BI	
Step 1	Cause of death	GSW	36	12	75.0
		BI	12	36	75.0
	Overall Percentage				75.0
a. The cut value is .500					

Using the body region variables identified in the multiple correspondence analysis results in a 75% correct identification rate overall, an increase of 25% from the model with only the constant. This is seen in Table 6-74.

The main assumption of binary logistic regression models is multicollinearity of the variables used in the model. To test this, linear regression is employed in SPSS, creating a collinearity table which can be interpreted easily.

Table 6-75: Collinearity assessment for analysis #2.

Coefficients[a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	Neurocranium	.412	2.429
	Maxillofacial	.456	2.194
	Mandible	.642	1.558
	Vertebrae	.751	1.332
	Left Shoulder Girdle	.847	1.181
	Right Shoulder Girdle	.750	1.334
	Left Upper Arm	.763	1.310
	Left Ribs	.505	1.979
	Right Ribs	.562	1.779
	Left Pelvis	.828	1.208
	Right Pelvis	.765	1.307
	Left femur	.861	1.162
	right femur	.781	1.280

a. Dependent Variable: Cause of death

To assess if any of the variable are collinear, the tolerance and VIF statistics are observed using the data in Table 6-75. Tolerance statistics are acceptable if the value is over 0.1 and the VIF is acceptable if its value is not over 10 (Field 2009). In this case, the lower tolerance is 0.434 and the largest VIF is 2.303 indicating no multicollinearity in the model.

Analysis #3

The third run of the binary logistic regression was undertaken with 100 cases subsampled (N= 52 gunshot wound cases).

Table 6-76: Hosmer and Lemeshow's Goodness-of-Fit for analysis #3.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	6.192	8	.626

The Hosmer and Lemeshow's statistic to evaluate the goodness-of-fit for the model had a significance of 0.626 for the third analysis, indicating a good model fit for the data. This is shown in Table 6-76.

Table 6-77: Statistics for variables included in the model using the block enter method for analysis #3.

Variables in the Equation								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Neurocranium(1)	-.832	.644	1.671	1	.196	.435	.123	1.536
	Mandible(1)	.162	.705	.053	1	.818	1.176	.295	4.683
	LShoulder(1)	-.834	.742	1.263	1	.261	.434	.101	1.860
	RShoulder(1)	-1.031	.648	2.532	1	.112	.357	.100	1.270
	LUpArm(1)	-.389	.742	.274	1	.600	.678	.158	2.905
	LRibs(1)	.371	.694	.286	1	.593	1.449	.372	5.647
	RRibs(1)	-.547	.725	.569	1	.450	.579	.140	2.396
	LPelvis(1)	.052	.666	.006	1	.937	1.054	.286	3.887
	RPelvis(1)	-.835	.655	1.628	1	.202	.434	.120	1.565
	RFemur(1)	.555	.740	.562	1	.453	1.742	.408	7.437
	LFemur(1)	-1.681	.582	8.330	1	.004	.186	.059	.583
	Maxillofacial(1)	.252	.666	.143	1	.705	1.287	.349	4.750
	Vertebrae(1)	.942	.544	3.002	1	.083	2.565	.884	7.446
	Constant	2.824	1.194	5.592	1	.018	16.846		
a. Variable(s) entered on step 1: Neurocranium, Mandible, LShoulder, RShoulder, LUpArm, LRibs, RRibs, LPelvis, RPelvis, RFemur, LFemur, Maxillofacial, Vertebrae.									

Table 6-77 shows the statistics for each body region variable including the coefficients for each, the Wald statistic and its significance and the Exp(B) value which will be used to interpret the odds for each variable associated with cause of death.

Table 6-78: Classification table for analysis #3.

Classification Table[a]					
			Predicted		
			Cause of death		
	Observed		GSW	BI	Percentage Correct
Step 1	Cause of death	GSW	42	10	80.8
		BI	20	28	58.3
	Overall Percentage				70.0
a. The cut value is .500					

The third analysis classification percentage was 70.0%, shown in Table 6-78, which was an increase of 48% from the constant only model, indicating an increase in the classification power of the model with the included body region variables.

Table 6-79: Multicollinearity assessment for analysis #3.

Coefficients[a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	Neurocranium	.494	2.024
	Maxillofacial	.559	1.788
	Mandible	.680	1.471
	Vertebrae	.783	1.276
	Left Shoulder Girdle	.703	1.423
	Right Shoulder Girdle	.724	1.382
	Left Upper Arm	.695	1.439
	Left Ribs	.498	2.009
	Right Ribs	.441	2.269
	Left Pelvis	.730	1.370
	Right Pelvis	.698	1.433
	Left femur	.863	1.159
	right femur	.653	1.532
a. Dependent Variable: Cause of death			

For the third analysis, no multicollinearity issues were identified when calculating the collinearity statistics, shown in Table 6-79. The smallest tolerance value is 0.441, which is well over the 0.100 threshold for multicollinearity. The largest VIF value is 2.269, which is below the 10.000 value which would again indicate a multicollinearity problem in the model.

Analysis #4

The fourth run of the binary logistic analysis was undertaken using a subsample of 94 cases identified using the syntax (N= 46 gunshot wound cases). The following tables represent the result of this analysis.

Table 6-80: Hosmer and Lemeshow's statistic for analysis #4.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	2.047	8	.980

Analysis #4, shown in Table 6-80, had a Hosmer and Lemeshow's goodness-of-fit statistic with a significance of 0.980, which indicated a very good fit for the model.

Table 6-81: Statistics for variables included in the model using the block enter method for analysis #4.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Neurocranium(1)	-.161	.627	.066	1	.797	.851	.249	2.906
	Mandible(1)	-.676	.781	.748	1	.387	.509	.110	2.353
	LShoulder(1)	.034	.653	.003	1	.958	1.035	.288	3.720
	RShoulder(1)	-1.991	.802	6.163	1	.013	.136	.028	.658
	LUpArm(1)	-.446	.767	.338	1	.561	.640	.142	2.879
	LRibs(1)	-.076	.605	.016	1	.900	.927	.283	3.034
	RRibs(1)	-.193	.639	.091	1	.763	.825	.236	2.886
	LPelvis(1)	-.012	.675	.000	1	.986	.988	.263	3.709
	RPelvis(1)	-1.418	.686	4.276	1	.039	.242	.063	.929
	RFemur(1)	.368	.762	.234	1	.629	1.446	.325	6.437
	LFemur(1)	-1.772	.616	8.266	1	.004	.170	.051	.569
	Maxillofacial(1)	.138	.673	.042	1	.837	1.148	.307	4.293
	Vertebrae(1)	.706	.594	1.414	1	.234	2.026	.633	6.492
	Constant	4.482	1.528	8.607	1	.003	88.452		
a. Variable(s) entered on step 1: Neurocranium, Mandible, LShoulder, RShoulder, LUpArm, LRibs, RRibs, LPelvis, RPelvis, RFemur, LFemur, Maxillofacial, Vertebrae.									

Table 6-81 shows the statistics for each body region variable including the coefficients for each, the Wald statistic and its significance and the Exp(B) value which will be used to interpret the odds for each variable associated with cause of death.

Table 6-82: Classification table for analysis #4.

Classification Table[a]					
			Predicted		
			Cause of death		
	Observed		GSW	BI	Percentage Correct
Step 1	Cause of death	GSW	34	12	73.9
		BI	16	32	66.7
	Overall Percentage				70.2

The classification table, shown in Table 6-82, demonstrates an increase in the classification percentage of the model from 51.1% to 70.2% correct, a difference of 19.1%.

Table 6-83: Multicollinearity assessment for analysis #4.

Coefficients[a]			
		Collinearity Statistics	
Model		Tolerance	VIF
1	Neurocranium	.581	1.720
	Maxillofacial	.628	1.592
	Mandible	.703	1.423
	Vertebrae	.746	1.340
	Left Shoulder Girdle	.779	1.284
	Right Shoulder Girdle	.748	1.337
	Left Upper Arm	.722	1.385
	Left Ribs	.673	1.485
	Right Ribs	.552	1.811
	Left Pelvis	.759	1.317
	Right Pelvis	.851	1.176
	Left femur	.825	1.213
	right femur	.640	1.563
a. Dependent Variable: Cause of death			

The multicollinearity test for analysis #4, in Table 6-83, indicates no issues in the collinearity of the body region variables, with the smallest tolerance value being 0.552 and the largest VIF value of 1.881.

Analysis #5

The fifth and final analysis to test the model was undertaken with 101 cases subsampled using the syntax (N= 53 cases of gunshot wound deaths).

Table 6-84: Hosmer and Lemeshow's goodness-of-fit statistic for analysis #5.

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	5.526	8	.700

The fifth analysis produced a goodness-of-fit statistic with a significance of 0.700, which indicated a model with fits the data well. This result is shown in Table 6-84

Table 6-85: Statistics for variables included in the model using the block enter method for analysis #5.

Variables in the Equation									
								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Neurocranium(1)	-.327	.665	.241	1	.623	.721	.196	2.657
	Mandible(1)	-.463	.782	.351	1	.554	.629	.136	2.914
	LShoulder(1)	-1.216	.756	2.591	1	.107	.296	.067	1.303
	RShoulder(1)	-1.193	.732	2.659	1	.103	.303	.072	1.273
	LUpArm(1)	-.382	.728	.275	1	.600	.682	.164	2.845
	LRibs(1)	1.024	.685	2.233	1	.135	2.785	.727	10.668
	RRibs(1)	-1.108	.670	2.734	1	.098	.330	.089	1.228
	LPelvis(1)	.619	.708	.766	1	.381	1.858	.464	7.435
	RPelvis(1)	-.522	.656	.633	1	.426	.593	.164	2.147
	RFemur(1)	-.078	.732	.011	1	.915	.925	.220	3.885
	LFemur(1)	-1.600	.592	7.309	1	.007	.202	.063	.644
	Maxillofacial(1)	.410	.663	.383	1	.536	1.507	.411	5.525
	Vertebrae(1)	1.148	.526	4.766	1	.029	3.152	1.125	8.834
	Constant	3.012	1.247	5.836	1	.016	20.329		
a. Variable(s) entered on step 1: Neurocranium, Mandible, LShoulder, RShoulder, LUpArm, LRibs, RRibs, LPelvis, RPelvis, RFemur, LFemur, Maxillofacial, Vertebrae.									

Table 6-85 shows the statistics for each body region variable including the coefficients for each, the Wald statistic and its significance and the Exp(B) value which will be used to interpret the odds for each variable associated with cause of death.

Table 6-86: Classification for analysis #5.

Classification Table[a]					
			Predicted		
			Cause of death		
	Observed		GSW	BI	Percentage Correct
Step 1	Cause of death	GSW	42	11	79.2
		BI	18	30	62.5
	Overall Percentage				71.3
a. The cut value is .500					

The classification table for analysis #5, in Table 6-86, indicated an increase in the percent of correct classification for the model from 52.5% for the constant only model to 71.3% for the model, which was an increase of 18.8%.

Table 6-87: Multicollinearity assessment for analysis #5.

Coefficients[a]			
Model		Collinearity Statistics	
		Tolerance	VIF
1	Neurocranium	.526	1.901
	Maxillofacial	.593	1.686
	Mandible	.684	1.461
	Vertebrae	.895	1.117
	Left Shoulder Girdle	.754	1.327
	Right Shoulder Girdle	.743	1.346
	Left Upper Arm	.792	1.263
	Left Ribs	.511	1.956
	Right Ribs	.514	1.945
	Left Pelvis	.679	1.473
	Right Pelvis	.645	1.550
a. Dependent Variable: Cause of death			

The multicollinearity assessment for analysis #5 indicated there were no collinearity issues for the body region variables included in the analysis, shown in Table 6-87. The lowest tolerance value was 0.511 and the highest VIF value was 1.956, well within the limits as outlined in (Field 2009).

6.5.3. Summary of binary logistic regression

Backward binary logistic regression

The following table summarises the relevant statistics to evaluate each of the models.

Table 6-88: Summary of statistics for backward binary logistic regression over five analyses.

Analysis #	Hosmer and Lemeshow's statistic	Classification Percentage
1	0.81	67.8
2	0.529	79.8
3	0.907	73.7
4	1	71.4
5	0.558	81.6
Average	0.7608	74.86
Max	1	81.6
Min	0.529	67.8

Table 6-88 summarises the Hosmer and Lemeshow's goodness-of-fit statistics and the classification percentage for the five analyses. Using the backward binary logistic regression technique the average Hosmer and Lemeshow's significance is 0.760, indicating good fit of the models produced. The classification percentage average is 74.86% indicating a positive increase in the classification power of the models.

Block enter binary logistic regression

The following table summarises the relevant statistics to evaluate the model for each of the five analyses.

Table 6-89: Summary of statistics for block enter binary logistic regression over five analyses.

Analysis #	Hosmer and Lemeshow's statistic	Classification Percentage
1	0.644	71.6
2	0.095	75
3	0.626	70
4	0.98	70.2
5	0.7	71.3
Average	0.609	71.62
Max	0.98	75
Min	0.095	70

Table 6-89 summarises the Hosmer and Lemeshow's goodness-of-fit statistics and the classification percentage for the five analyses. Using the block enter binary logistic regression technique the average Hosmer and Lemeshow's significance is 0.609, indicating good fit of the models produced. The classification percentage average is 71.62% indicating a positive increase in the classification power of the models.

Comparison of the two methodologies of binary logistic regression

To compare the two methods of binary logistic regression for the gunshot wound and blast injury data, the Hosmer and Lemeshow's statistic and the classification percentage were compared using independent samples *t*-test.

Table 6-90: t-Test comparing backward binary logistic regression and block enter binary logistic regression results.

Independent Samples Test										
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Classification	Equal variances assumed	7.138	.028	1.186	8	.269	3.240000000	2.730933906	-3.057544881	9.537544881
	Equal variances not assumed			1.186	4.958	**.289**	3.240000000	2.730933906	-3.797838919	10.277838919
HLStat	Equal variances assumed	.090	.772	.886	8	**.402**	.151800000	.171391773	-.243430138	.547030138
	Equal variances not assumed			.886	6.890	.406	.151800000	.171391773	-.254787692	.558387692

The *t*-Test shows no significant difference between the two methods, shown in Table 6-90. For the classification results the statistics are t (8) = 1.186, p= 0.289. For the Hosmer and Lemeshow's statistic, there was also no significant difference t (8) = 0.886, p= 0.402.

6.6. Comparison of Bosnia sample with World War One blast injury cases

The World War One sample was identified from the Canadian circumstances of death records and represents a sample which has trauma from mortars. It was selected to compare with the Bosnia sample based on the lack of protective armour in the troops. This made the sample comparable with the Bosnia sample, which is composed of what is believed to be civilians who therefore had no access to protective armour which could influence the pattern of injury, as is found in modern conflict (examined in the next section). During World War One, the Canadian army typically wore the same uniforms as the British, which did not include personal protective pieces (Chartrand and Embleton 2007).

The samples were compared using the Pearson' χ^2 to test for any significant difference over multiple variables, employing a Holm- Bonferroni correction. Comparing these two samples, it is found that there were significant differences between the two samples. The vertebrae, the upper limb, the pelvis and the lower limb were found to be significantly different; however the head and the torso were not. The results are presented subsequently.

Vertebrae

Table 6-91: Contingency table presenting the prevalence counts for vertebral trauma in the Bosnia and World War One samples.

BodyRegion * Context Crosstabulation					
			Context		
			Bosnia	WW1	Total
BodyRegion	Vertebrae	Count	17	20	37
		Expected Count	9.4	27.6	37.0
		% within BodyRegion	45.9%	54.1%	100.0%
		% within Context	35.4%	14.2%	19.6%
		% of Total	9.0%	10.6%	19.6%
	Vertebrae No Trauma	Count	31	121	152
		Expected Count	38.6	113.4	152.0
		% within BodyRegion	20.4%	79.6%	100.0%
		% within Context	64.6%	85.8%	80.4%
		% of Total	16.4%	64.0%	80.4%
Total		Count	48	141	189
		Expected Count	48.0	141.0	189.0
		% within BodyRegion	25.4%	74.6%	100.0%
		% within Context	100.0%	100.0%	100.0%
		% of Total	25.4%	74.6%	100.0%

There was a significant difference between the two samples when examining the presence and absence of trauma to vertebrae χ^2 (1, N= 189), *p*= .002, shown in Table 6-91. This was significant after Holm-Bonferroni correction. Vertebral trauma was much more prevalent in the Bosnia sample than in the World War One sample, more than double the latter's 14.2% prevalence.

Upper limb

Table 6-92: Contingency table presenting the prevalence counts for upper limb trauma in the Bosnia and World War One samples.

BodyRegion * Context Crosstabulation					
			Context		Total
			Bosnia	WW1	
BodyRegion	Upper Limb	Count	33	32	65
		Expected Count	16.5	48.5	65.0
		% within BodyRegion	50.8%	49.2%	100.0%
		% within Context	68.8%	22.7%	34.4%
		% of Total	17.5%	16.9%	34.4%
	Upper Limb No Trauma	Count	15	109	124
		Expected Count	31.5	92.5	124.0
		% within BodyRegion	12.1%	87.9%	100.0%
		% within Context	31.3%	77.3%	65.6%
		% of Total	7.9%	57.7%	65.6%
Total		Count	48	141	189
		Expected Count	48.0	141.0	189.0
		% within BodyRegion	25.4%	74.6%	100.0%
		% within Context	100.0%	100.0%	100.0%
		% of Total	25.4%	74.6%	100.0%

A significant difference between the trauma in the upper limb in the Bosnia and World War One samples was found χ^2 (1, N= 189), p= 0.000, with Holm-Bonferroni correction, shown in Table 6-92. Prevalence was very high in the Bosnia sample comparatively to the World War One sample (68.8% versus 22.7%).

Pelvis

Table 6-93: Contingency table presenting the prevalence counts for pelvis trauma in the Bosnia and World War One samples.

BodyRegion * Context Crosstabulation					
			Context		
			Bosnia	WW1	Total
BodyRegion	Pelvis	Count	22	11	33
		Expected Count	8.4	24.6	33.0
		% within BodyRegion	66.7%	33.3%	100.0%
		% within Context	45.8%	7.8%	17.5%
		% of Total	11.6%	5.8%	17.5%
	Pelvis No Trauma	Count	26	130	156
		Expected Count	39.6	116.4	156.0
		% within BodyRegion	16.7%	83.3%	100.0%
		% within Context	54.2%	92.2%	82.5%
		% of Total	13.8%	68.8%	82.5%
Total		Count	48	141	189
		Expected Count	48.0	141.0	189.0
		% within BodyRegion	25.4%	74.6%	100.0%
		% within Context	100.0%	100.0%	100.0%
		% of Total	25.4%	74.6%	100.0%

Trauma in the pelvis area was found nearly six times more often in the Bosnia sample than in the World War One sample, shown in Table 6-93. This difference was found to be significant χ^2 (1, N= 189), p= 0.000.

Lower limb

Table 6-94: Contingency table presenting the prevalence counts for lower limb trauma in the Bosnia and World War One samples.

BodyRegion * Context Crosstabulation					
			Context		
			Bosnia	WW1	Total
BodyRegion	Lower Limb	Count	29	45	74
		Expected Count	18.8	55.2	74.0
		% within BodyRegion	39.2%	60.8%	100.0%
		% within Context	60.4%	31.9%	39.2%
		% of Total	15.3%	23.8%	39.2%
	Lower Limb No Trauma	Count	19	96	115
		Expected Count	29.2	85.8	115.0
		% within BodyRegion	16.5%	83.5%	100.0%
		% within Context	39.6%	68.1%	60.8%
		% of Total	10.1%	50.8%	60.8%
Total		Count	48	141	189
		Expected Count	48.0	141.0	189.0
		% within BodyRegion	25.4%	74.6%	100.0%
		% within Context	100.0%	100.0%	100.0%
		% of Total	25.4%	74.6%	100.0%

In the lower limb, twice the amount of trauma was found in the Bosnia sample than in the World War One sample, shown in Table 6-94. This was found to be a significant difference χ^2 (1, N= 189), p= 0.001.

Summary

The regions found to be significantly different were the vertebrae, upper limb, pelvis and lower limb. This is shown in Figure 6-32: Areas of significant difference between the World War One sample and the Bosnia sample.

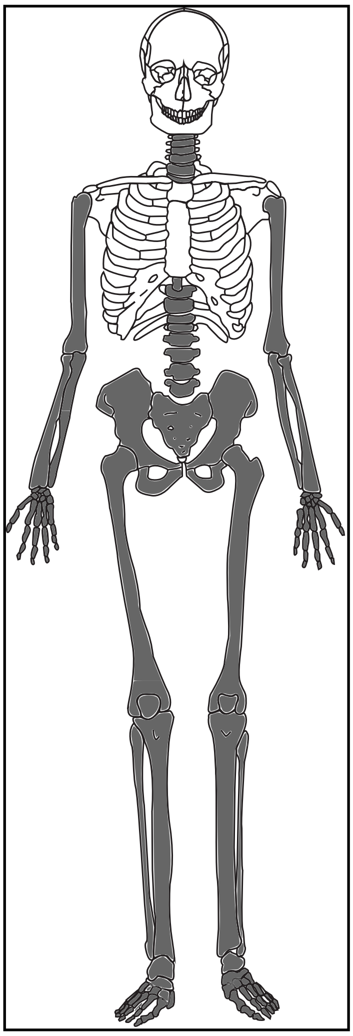

Figure 6-32: Areas of significant difference between the World War One sample and the Bosnia sample.

6.7. Comparisons of Bosnia sample and clinical literature data

To examine the patterns of injury in the clinical literature and compare them to the ones from the Bosnia sample, the literature was consulted to locate prevalence figures in various situations and compare these statistically using the Pearson's χ^2 test. Three situations were identified which could provide data that could be used. The prevalence figure was collected along with sample sizes to calculate the number of cases with trauma to the body region variables so that these may be compared between the samples. Figures with significant differences are reported below, after correcting for multiple pairwise tests using the Holm-Bonferroni correction.

6.7.1. Combat

Articles detailing prevalence of blast trauma to various body regions were identified and were previously discussed in the literature review. This includes cases of improvised explosive devices, roadside bombs and under vehicle explosions. Additionally, journal articles identifying the prevalence of trauma in previous conflicts were included along with modern conflict.

Vietnam

The first examination made was with data from the Ramasamy (2009) paper which provides information for various historical conflicts. Within this data, all body regions used for comparison were found to be significant.

For the head, neck and face region, the results were χ^2 (1, N=36788), p= 0.000. In the Bosnia sample, 50% of cases had trauma in this region, compared to 20.6% in the Vietnam data. The following variable was the thorax and back. This was also significant χ^2 (1, N= 36788), p= 0.00. For this variable, 47.9% of the Bosnia cases were identified as having trauma and only 8.8% in the Vietnam cases.

The presence of upper limb trauma was compared and a significant difference was found χ^2 (1, N= 36788), p= 0.000. In this comparison, the Bosnia cases were found to have trauma to the upper limb in 68.8% of cases versus 27.2% of the Vietnam cases. The difference between lower limb prevalence in the Vietnam and Bosnia samples was significant χ^2 (1, N= 36788), p= 0.008. Again, the difference in prevalence between Bosnia and Vietnam for lower limb trauma was quite large, 60.4% and 40.9% respectively. This is summarised in Figure 6-33.

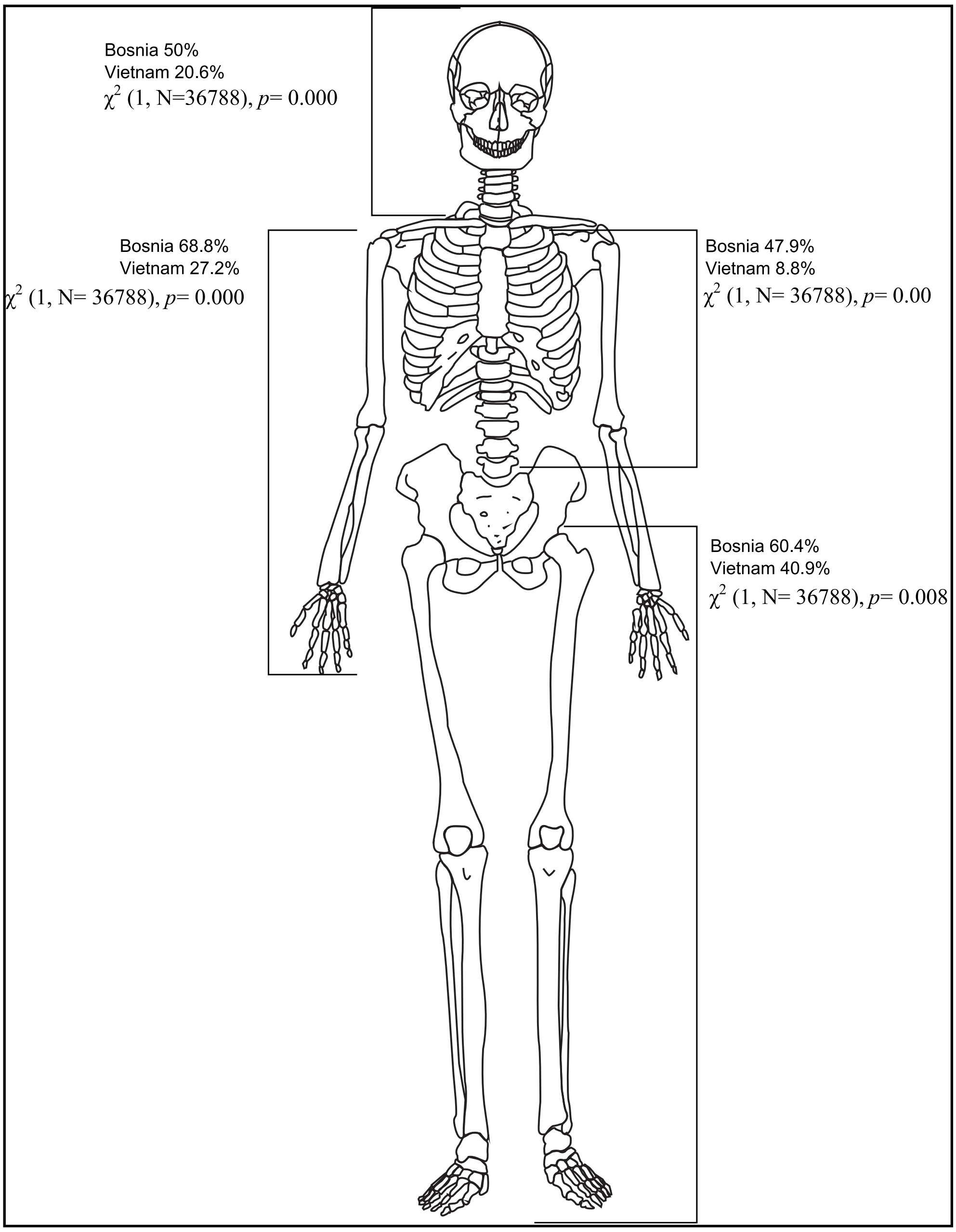

Figure 6-33: Comparison of prevalence of trauma in a sample from Bosnia and a sample from Vietnam (Ramasamy 2009). Areas significantly different were the head, neck and face, the thorax and back, as well as the upper and lower limbs. Prevalence of trauma was also higher in the Bosnia sample, for all body regions.

Northern Ireland

Comparison of the results from the Ramasamy (2009) article with data on the conflict in Northern Ireland was also undertaken. Three variables were compared. They were a combined head, neck and face variable, a thorax and back variable and the upper limbs.

Table 6-95shows the results of the χ^2 (1, N= 717) which had a significant difference between the two samples.

Table 6-95: Northern Ireland- Variables and associated significance level for χ2 (1, N= 717), with the Holm-Bonferroni corrected α-level to assess significance.

Variable	*p*-value	α level (Holm-Bonferroni corrected)
Head, Neck and face	0	0.0167
Thorax and back	0	0.025
Upper limbs	0.362	0.05

In this comparison, two variables were found to be significant. These were the head, neck and face variable as well as the thorax and back variable. In the Bosnia sample, the prevalence of head neck and face was 50% of the sample (N=24), compared to 13.2% in the Northern Ireland sample (N= 88). For the thorax and back, the Bosnia sample had trauma in 47.9% of cases (N=23) and in Northern Ireland, this trauma was seen in 16.6% of cases (N=111). The results are shown in Figure 6-34.

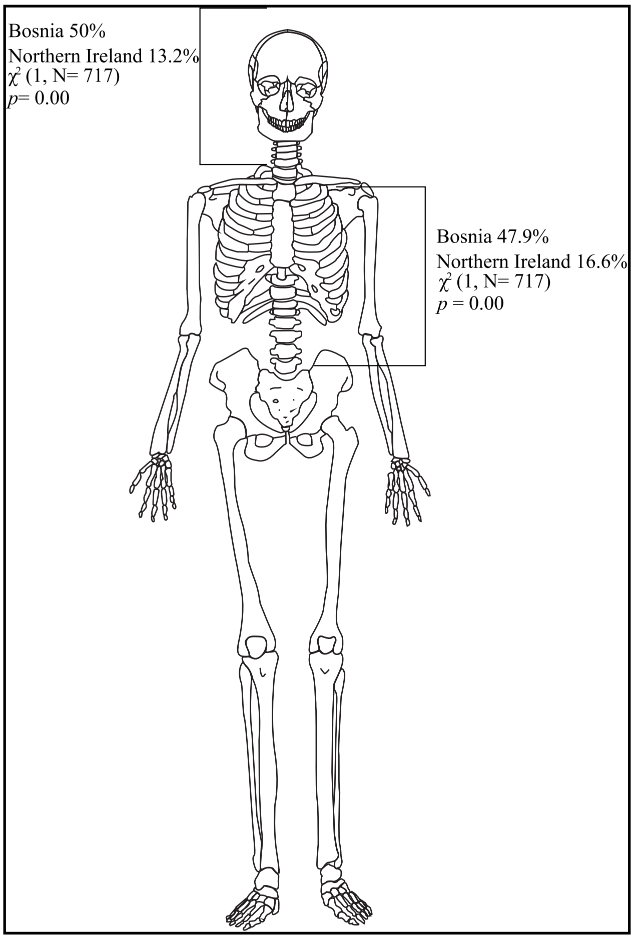

Figure 6-34: Prevalence of trauma in the Bosnia sample compared to a sample from Northern Ireland (Ramasamy 2009). Prevalence higher in the Bosnia sample and was significantly different in the head, neck and face as well as the thorax and back region.

A second study on Northern Ireland was also examined (Mellor 1992). This study only examined the presence of trauma in the upper or lower limb. In both these body regions, there was a significant difference between the two samples. For the upper limb the Bosnia sample had a prevalence of 68.8% (N= 48) with 29.9% of cases with upper limb trauma in Northern Ireland (N=298), χ^2 (1, N=346), *p*= 0.000. The lower limb prevalence was 60.4% in Bosnia (N=48) and 35.6% in the Northern Ireland sample (N=298). This was significantly different χ^2 (1, N= 346), *p*= 0.001. This is shown in Figure 6-35, below.

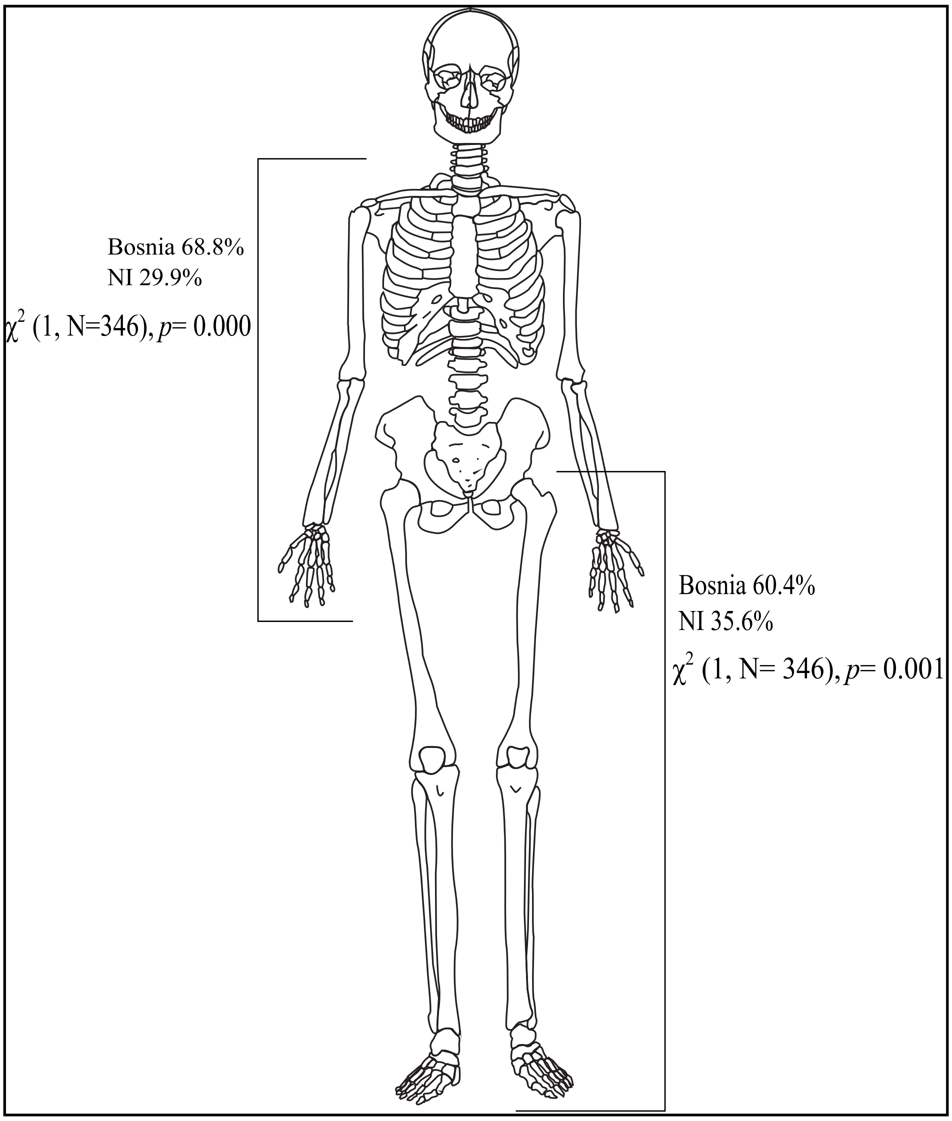

Figure 6-35: Prevalence of trauma in the Bosnia sample compared to a sample from Northern Ireland (Mellor 1992). Prevalence higher in the Bosnia sample and was significantly different in the upper limb as well as the lower limb region.

Iraq and Iran War

Sadda (2003) examined maxillofacial injuries from the Iraq and Iran War during the time period between 1980 and 1988. This was a sample of 300 cases an examined trauma to the lower third of the face and the mandible. The lower third of the face was not significantly different between the two samples χ^2 (1, N= 348), p = 0.591. For the mandible, this was found to be significantly different between the two samples χ^2 (1, N= 348), p= 0.006. In the Bosnia sample, 18.8% of cases had mandibular trauma (N=48). For the sample from the Iraq and Iran war 40.3% of cases had mandibular trauma (N=300).

Lebanon

Gofrit and colleagues (1996) analysed the trauma patterns from the Lebanon war, with a sample of wounded from 1982. Four variables were examined and compared to the Bosnia sample. All four were found to be significant χ^2 (1, N= 212), p= 0.000. Prevalence figures are listed in Table 6-96.

Table 6-96: Prevalence of trauma for each body region comparing the Bosnia and Gofrit et al.'s sample from the Lebanon war in 1982.

Sample/Variable	Face	Head and neck	Torso	Extremities
Bosnia (N=48)	70.8%	50%	47.9%	91.7%
Gofrit *et al.* 1996 (N= 164)	34.8%	11.6%	84.1%	40.2%

The results are shown in Figure 6-36, examining the body regions compared.

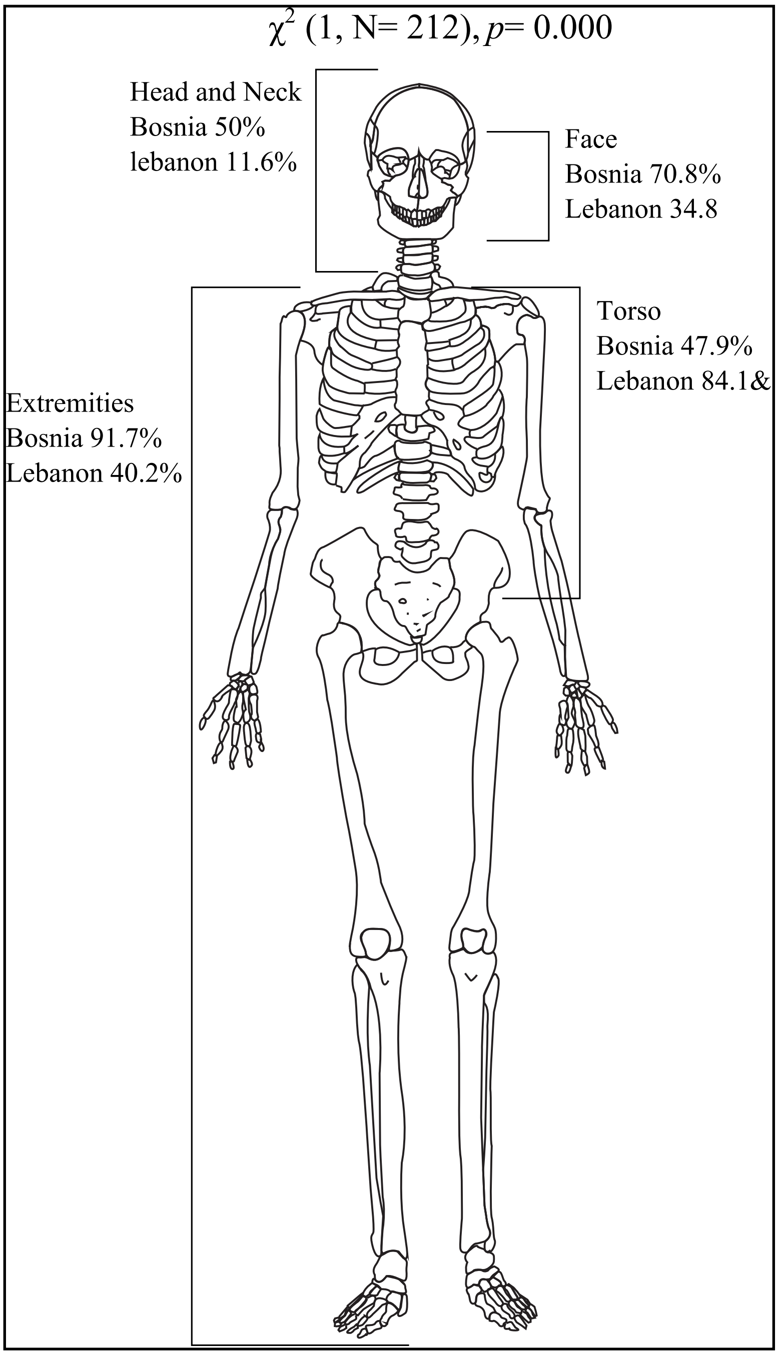

Figure 6-36: Comparison of prevalence of blast trauma in the Bosnia sample and a sample from Lebanon in 1982 (Gofrit *et al.* 1996). All areas were found to be significantly different.

Gulf War (1990)

Ramasamy and colleagues (2009) reported figures for the first Gulf War. Five variables were compared with the Bosnia sample and the reported significance values are presented in Table 6-97 for χ^2 (1, N = 203).

Table 6-97: p-values for variables compared between Gulf War trauma prevalence and Bosnia prevalence.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Thorax and back	0	0.001
Upper limbs	0	0.0125
Pelvis	0	0.0167
Head, neck and face	0.001	0.025
Lower limbs	0.007	0.05

Table 6-98shows the prevalence for each body region in each sample.

Table 6-98: Prevalence of trauma for each body region comparing the Bosnia and Ramasamy et al.'s sample from the first Gulf War in 1990.

Variable/Sample	Bosnia (N= 48)	Ramasamy *et al.* (N= 155)
Thorax and back	5.8%	47.9%
Upper limbs	68.8%	30.3%
Pelvis	45.8%	0.6%
Head, neck and face	50.0%	76.1%
Lower limbs	60.4%	37.4%

All variables were found to be significantly different between the two samples. The results are shown in Figure 6-37, showing the areas which were significantly different and highlighting the prevalence of trauma in each.

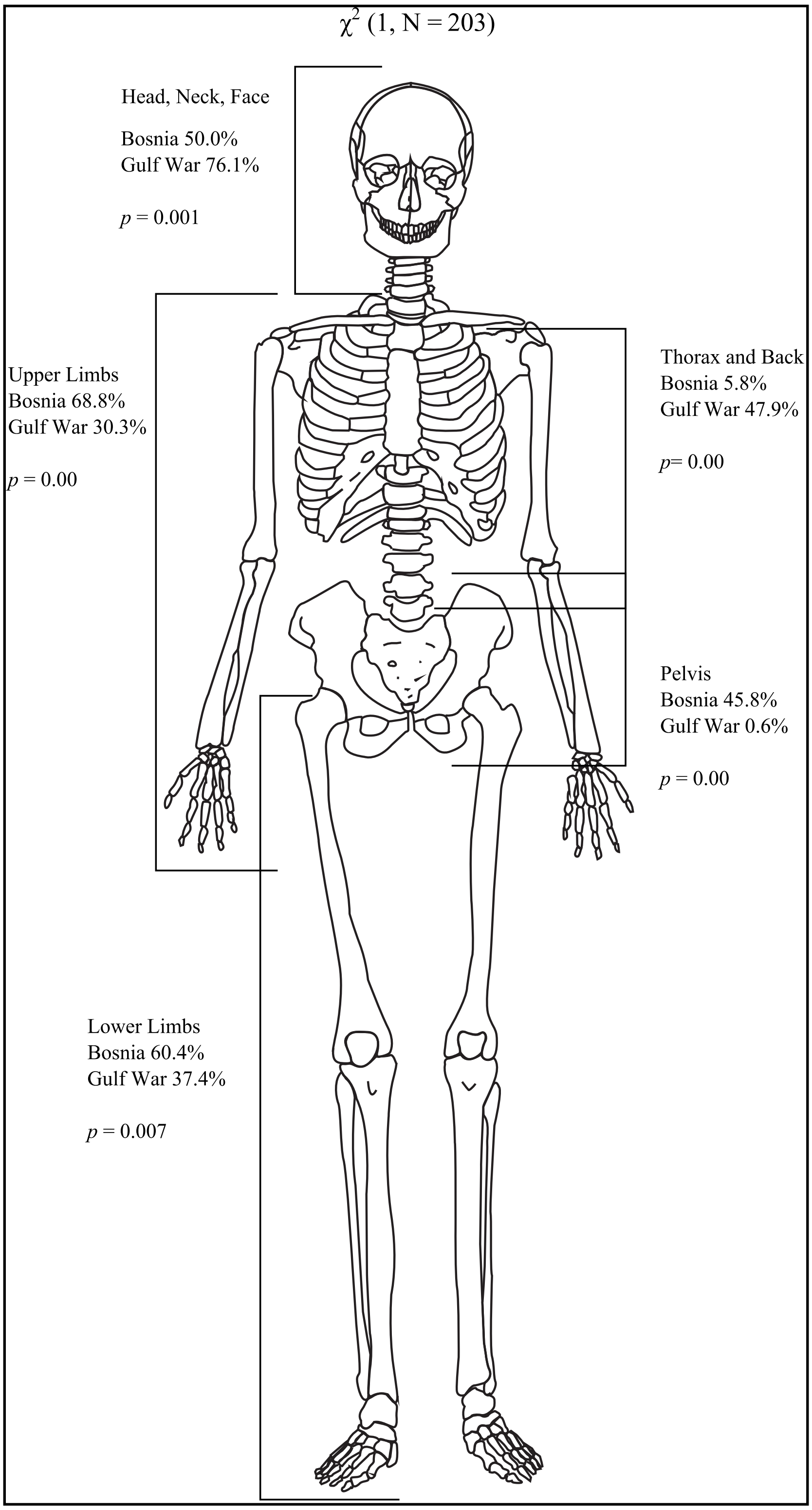

Figure 6-37: Areas of significant difference between the Bosnia sample and a sample from the Gulf War in 1990 (Ramasamy *et al.*). For the Gulf War, trauma was significantly more prevalent in the head and torso regions. Conversely, trauma was more prevalent to the upper limb, pelvis and lower limb in the Bosnia sample, significantly so.

Operation Iraqi Freedom

One study was identified which presented trauma patterns from the modern conflict starting in 2003 and currently ongoing. This study by Belmont (2010) examined trauma prevalence in the head and neck region and found that there was no significant difference between the two samples χ^2 (1, N=438), *p*= 0.082. Head and neck trauma was found 50% of the Bosnia sample (N=48) and in 36.2% of the Belmont study (N= 390).

A second study examined the trauma patterns associated with improvised explosive devices in Iraq during 2006. Five variables were identified in the (Ramasamy et al. 2009) paper. These are presented in Table 6-99 along with their respective *p*- values and the Holm-Bonferroni corrected α level.

Table 6-99: p-values for variables compared between (Ramasamy et al. 2009) trauma prevalence and Bosnia prevalence.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Chest and back	0.001	0.01
Lower limb	0.004	0.0125
Upper limb	0.041	0.017
Head and neck	0.136	0.025
face	1	0.05

Table 6-100: Prevalence figures for five body regions comparing Bosnia and Operation Iraqi Freedom trauma.

Variable/Sample	Bosnia (N= 48)	Ramasamy *et al.* (N= 42)
Upper Limb	68.8%	88.1%
Lower limb	60.4%	88.1%
Face	29.2%	31.0%
Head and neck	50%	66.7%
Chest and back	47.9%	14.3%

It was found that the chest and back variable was significantly different, along with the lower limb variable. The prevalence figures for each body region is shown in Table 6-100.

Afghanistan

Ramasamy *et al.* (2010) examined blast-related fracture patterns and published data regarding patters in an enclosed context, examining trauma to the extremities. Five parts of the extremities were examined: feet, femur, tibia and fibula, humerus and hand. Following Holm-Bonferroni correction, two body regions were found to be significantly different between the two samples. Prevalence of trauma to the feet was significantly different χ^2 (1, N= 76), p= 0.000. In the Bosnia sample, prevalence was 2.1% (N = 48). Conversely, in the Afghanistan sample (N = 28) the prevalence was 35.7%.

Additionally, significant difference was found in the prevalence of trauma in femur trauma χ^2 (1, N= 76). Prevalence in the Afghanistan sample was found to be 10.7% (N = 28) and 39.6% in the Bosnia sample (N = 48). The results are shown in Figure 6-38.

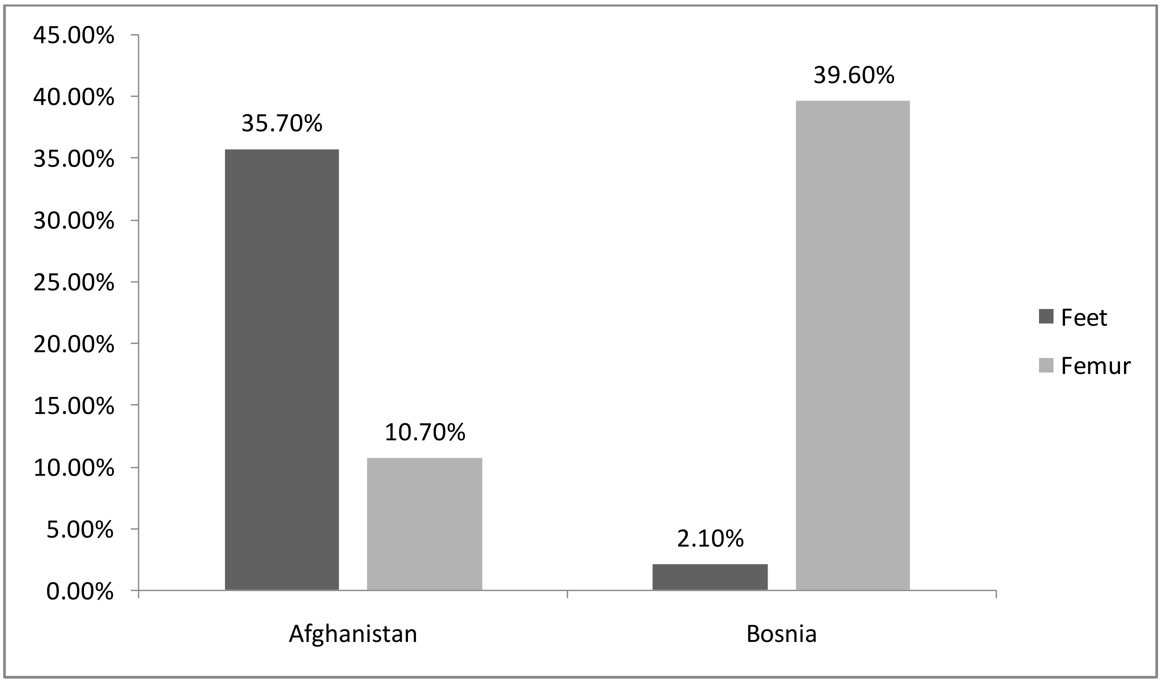

Figure 6-38: Prevalence of trauma to the femur and feet in Afghanistan and Bosnia.

6.7.2. Terrorist incidents

Comparison of terrorist incidents described in the literature was undertaken to examine similarities and differences in between the Bosnia sample and those from various locations and contexts.

U.S.S. Cole

Lambert and colleagues (2003) described the orthopaedic injuries in the survivors of the terrorist attack on the U.S.S. Cole in 2000. The lower limb trauma prevalence was compared and no significant difference between the Bosnia sample and the U.S.S. Cole sample χ^2 (1, N= 87), p= 1.000. Prevalence of orthopaedic trauma to the lower limb was noted as 60.4% in the Bosnia sample (N= 48) and 61.5% in the U.S.S. Cole (N = 39).

Oklahoma City

On April 19, 1995 the Alfred P. Murrah Federal building was bombed using ammonium nitrate. Mallonee and colleagues (Mallonee et al. 1996) described the patterns of injury in the fatalities and survivors. This data was compared and significant differences were found for two variables. Table 6-101shows the p-values for the body region comparisons as well as the Holm-Bonferroni corrected α- level.

Table 6-101: p-values for variables compared between (Mallonee et al. 1996) trauma prevalence and Bosnia prevalence to the upper limbs, torso, lower limbs, head and neck. Holm- Bonferroni corrected α level is included.

Variable	p- value	α level (Holm-Bonferroni corrected)
Upper limb	0.002	0.0125
Torso	0.016	0.0167
Lower limb	0.052	0.025
Head and neck	0.177	0.05

The upper limbs and torso comparisons were significantly different. For the upper limb, prevalence of trauma was 68.8% in Bosnia (N = 48) and 38.3% in the Oklahoma City bombing (N = 60), χ^2 (1, N = 108), *p*= 0.002. Torso trauma was found in 47.9% of cases in Bosnia (N = 48) and 25.0% of cases from the Oklahoma sample (N =60). This was a significant difference χ^2 (1, N= 108), *p*= 0.016. The differences in prevalence are shown in Figure 6-39.

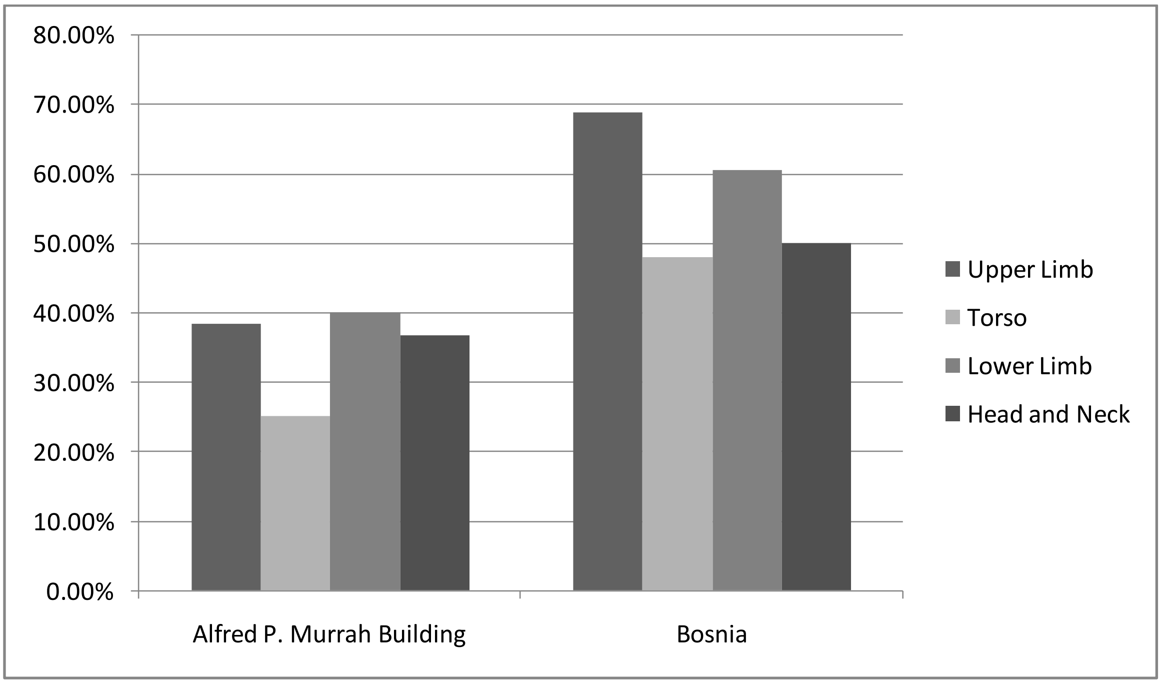

Figure 6-39: Regions of significant difference in prevalence of trauma comparing the Oklahoma bombing and the Kravica warehouse sample. The upper limb was significantly different with a higher prevalence in Bosnia (χ^2 (1, N = 108), *p*= 0.002). The higher prevalence of trauma to the torso in the Bosnia sample was also significant (χ^2 (1, N= 108), *p*= 0.016).

Birmingham pub bombings

Waterworth and Carr's (1975) paper about the pub bombings analysed 21 victims post-mortem. The data was compared to the Bosnia data and is summarised in the following, Figure 6-40 and Table 6-102.

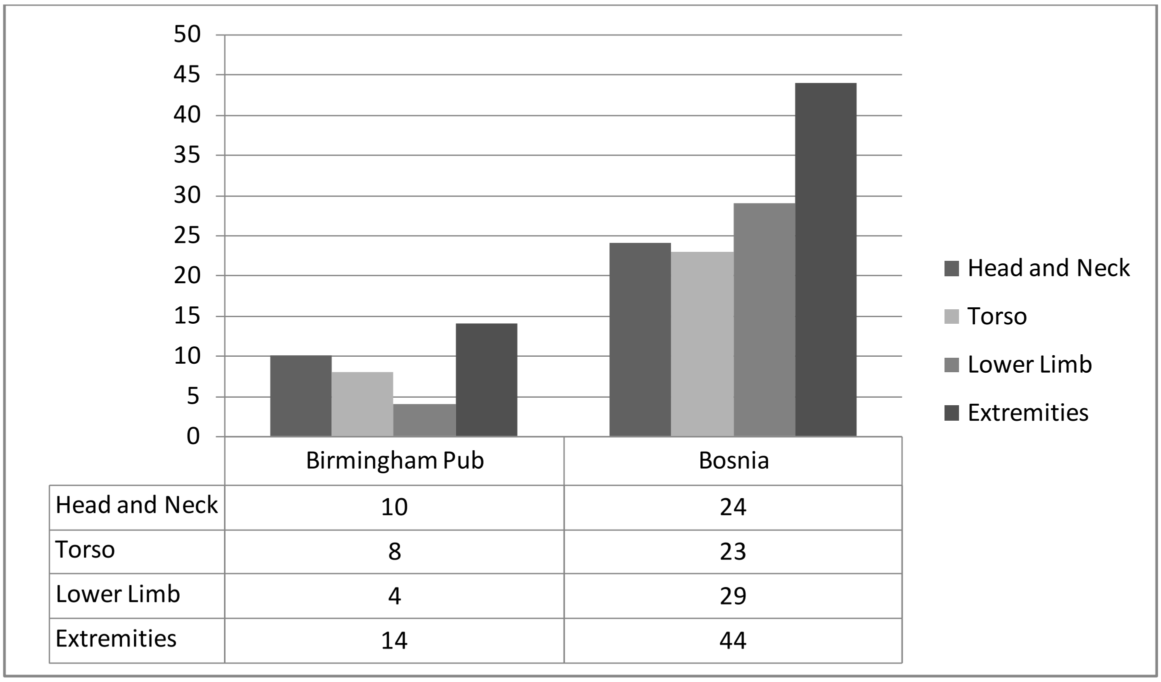

Figure 6-40: Number of victims with trauma comparing the Birmingham pub bombings (Waterworth and Carr 1975) and the Kravica warehouse case.

Table 6-102: p-values for variables compared between the Birmingham pub bombings (Waterworth and Carr 1975) trauma prevalence and Bosnia prevalence to the upper limbs, torso, lower limbs, head and neck. Holm- Bonferroni corrected α level is included.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Lower limb	0.002	0.0125
Extremities	0.027	0.0167
Torso	0.6	0.025
Head and neck	1	0.05

The only variable found to be significantly different was the difference in prevalence of trauma to the lower limb. In Bosnia, 60.4% of cases had trauma (N= 48) to the lower limb. In the pub bombings, 19.0% were found to have lower limb trauma (N= 21).

Israel

Weil and colleagues (Weil et al. 2011) studied a total of 1245 casualties with blast and gunshot trauma from terrorist activities. The data about regarding the blast injury cases was collected and compared to the data from Bosnia, seen in Figure 6-41: Prevalence of trauma in the Kravica warehouse sample and the Israeli sample and Table 6-103: Prevalence of each variable in the Bosnia and Israel samples.

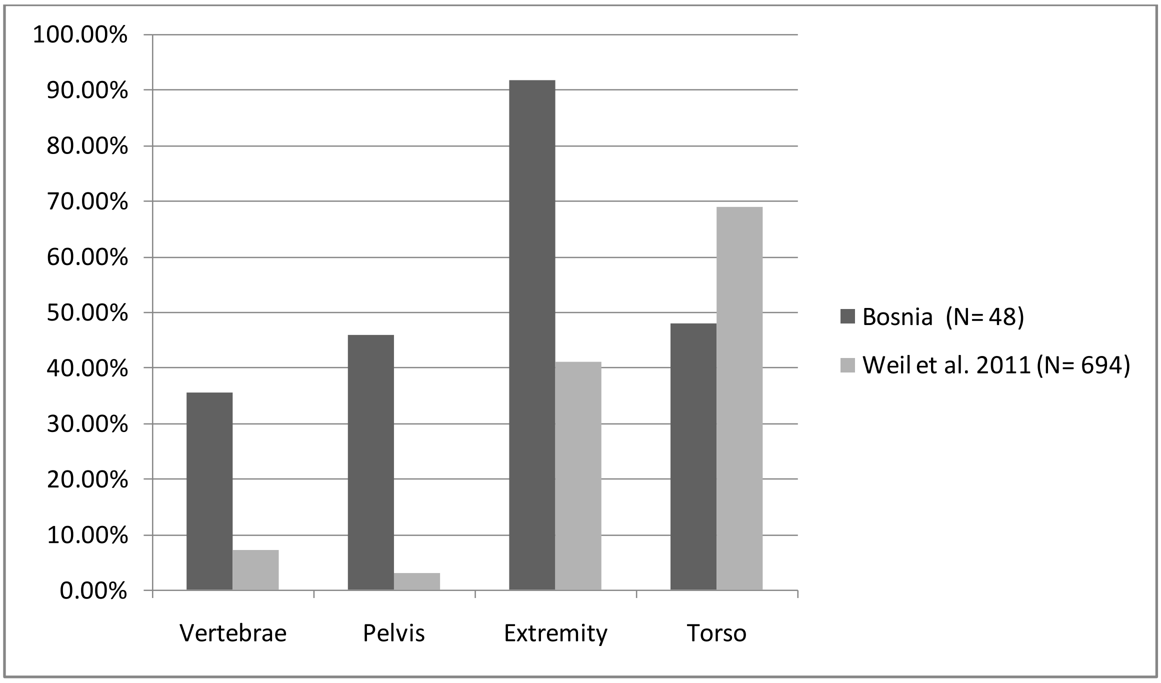

Figure 6-41: Prevalence of trauma in the Kravica warehouse sample and the Israeli sample.

Table 6-103: Prevalence of each variable in the Bosnia and Israel samples.

Variable/Sample	Bosnia (N= 48)	Weil *et al*. 2011 (N= 694)
Vertebrae	35.4%	7.1%
Pelvis	45.8%	3.0%
Extremity	91.7%	41.1%
Torso	47.9%	69.0%
Headneck	50%	69.0%

Table 6-104: p-values for variables compared between (Weil et al. 2011) trauma prevalence and Bosnia prevalence to the upper limbs, torso, lower limbs, head and neck. Holm- Bonferroni corrected α level is included.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Vertebrae	0	0.001
Pelvis	0	0.0125
Extremity	0	0.0167
Torso	0.004	0.025
Headneck	0.007	0.05

All variables examined were found to be significantly different. Prevalence was much higher in the vertebrae, pelvis and extremities in Bosnia and opposite in Israel for the torso and neck.

Northern Ireland

Hadden and colleagues (1978) examined data on civilian terrorism injuries in Northern Ireland. They examined injury to extremity areas. Comparing this data to the prevalence figures in Bosnia yielded significant differences in the hand and foot. This is shown in Table 6-105. Differences in trauma prevalence in the pectoral girdle, femur and humerus were not significant.

Table 6-105: p-values for variables compared between Hadden et al. 1978 trauma prevalence and Bosnia prevalence to the hand, foot, forearm and tibia and fibula. Holm- Bonferroni corrected α level is included.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Hand	0	0.007
Foot	0	0.0083
Forearm	0.093	0.01
Tibia and Fibula	0.128	0.0125

For the hand variable, prevalence in the Bosnia sample was 8.3% (N= 48) and 55.6% in the (Hadden et al. 1978) sample (N= 18). The foot was found to have trauma in 2.1% if cases (N= 48) and 31.3% of Northern Ireland cases (N= 32). The forearm was injured in 35.4% of Bosnia cases (N= 48) and 61.1% of Northern Ireland cases (N= 18). The tibia and fibula were also examined between the two samples. In the Bosnia sample, 20.8% of cases had trauma to the lower legs (N=48). In the Hadden and colleagues' (1978) sample, 37.5% of cases had trauma (N= 32).

Further data in the same paper examined 62 cases of trauma in the head and neck region. Comparing this to the Bosnia sample, a significant difference in skull trauma was found χ^2 (1, N= 110), p= 0.001. In the Bosnia sample, 47.9% of cases (N= 48) had trauma to this region. The terrorism sample was found to have skull trauma in 17.7% of cases (N= 62).

Paris

Rignault and Deligny (1989) studied 11 terrorist bombings that occurred in Paris between December 1985 and September 1986. The data from these bombings was compared to the data from Bosnia. Four body regions were examined, with three found to be significantly different, shown in Table 6-106.

Table 6-106: p-values for variables compared between the Rignault and Deligny (1989) trauma prevalence and Bosnia prevalence to the hand, foot, forearm and tibia and fibula. Holm- Bonferroni corrected α level is included.

Variable	*p*- value	α level (Holm-Bonferroni corrected)
Thorax	0	0.0125
Upper limb	0.001	0.0167
Head and neck	0.002	0.025
Lower limb	0.079	0.05

Aside from the lower limb, the variables were significant χ^2 (1, N= 102). Prevalence figures are presented below in Table 6-107: Prevalence of trauma in the Bosnia and Paris samples. and Figure 6-42: Prevalence of trauma to the thorax, upper limb and head and neck in the Kravica warehouse sample and the 11 cases studied in the Rignault and Deligny study of bombings in Paris.

Table 6-107: Prevalence of trauma in the Bosnia and Paris samples.

Variable/Sample	Bosnia (N= 48)	(Rignault and Deligny 1989) (N= 54)
Thorax	47.9%	3.7%
Upper limb	68.8%	33.3%
Head and neck	50%	20.4%

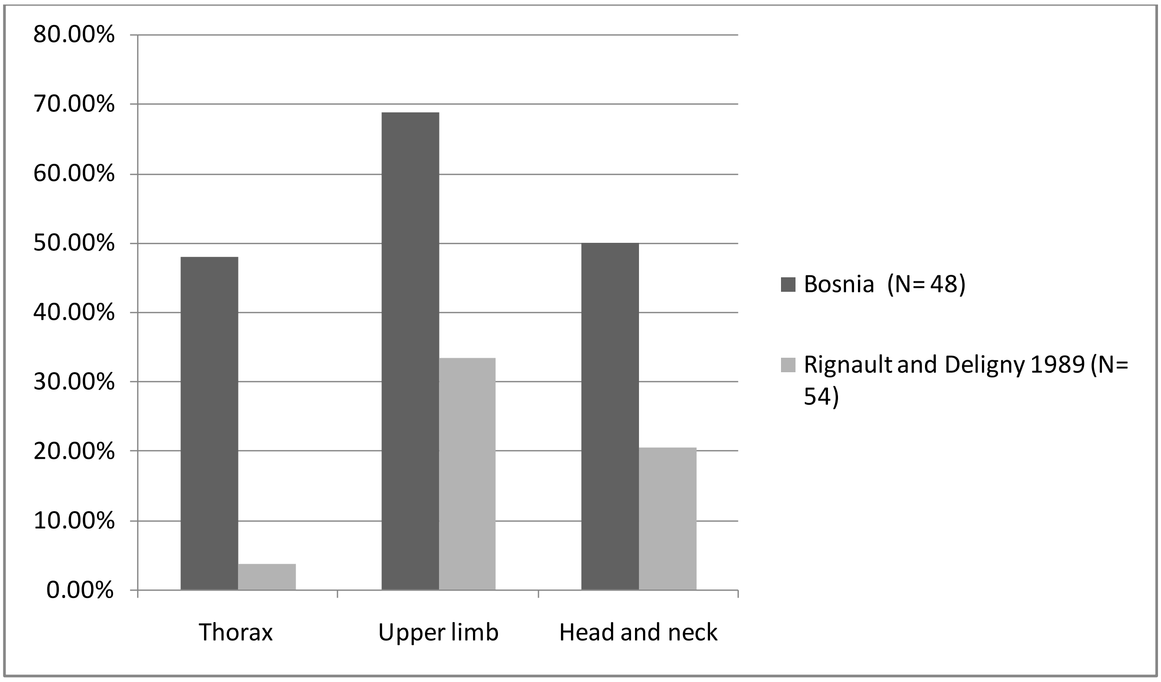

Figure 6-42: Prevalence of trauma to the thorax, upper limb and head and neck in the Kravica warehouse sample and the 11 cases studied in the Rignault and Deligny study of bombings in Paris. Prevalence in these three variables was always higher in the Bosnia sample.

6.8. Summary of the results chapter

In this chapter, the results of the analyses performed on the data collected from the ICMP files were presented. Descriptive statistics were used to quantify the groups within the samples. These are found in section 6.1.

Pearson's χ^2 – Comparing presence of trauma between blast injury and gunshot wound cause of death

The first analysis undertaken was examining associations between body region variables and cause of death (blast injury and gunshot wounds). This was accomplished using Pearson's χ^2 and applying the Holm-Bonferroni method of correction for multiple comparisons. These tests showed that there were significant differences in some of the body region variables between the blast injury and gunshot wound causes of death. The variables which were significantly different between the two were: left forearm (medium effect size), left femur (small effect size), bilateral side trauma (small effect size), and unsided trauma (small effect size). In the case of left forearm, left femur and bilateral trauma, the prevalence was significantly higher in the blast injury cases. In the gunshot wound cases, the presence of unsided trauma was significantly different to that in blast injury.

Cluster analysis

When clustering the samples according to cause of death, the blast injury sample demonstrated a two-cluster solution, with only two cases in the second cluster (GL01/375B and GL01/541B). For the gunshot wound cases, a four cluster solution was found. The second, third and fourth clusters were also very small, with individual cases.

Secondly, cluster of the gunshot wound cases (using a subsampling syntax) were analysed with the blast injury cases. Using this methodology, binary cluster analysis was undertaken a total of 11 times. The results indicated that the optimal number of clusters was 2, 4 or 5. The two cluster solution was most common, being the result of the analysis in 7 of the 11 times it was undertaken. For each of these analyses, the majority of the cases clustered into one large group along with a small number of cases being assigned to subsequent clusters, sometimes just singular cases. These cases are identified for each analysis in 6.3.2 Clustering cases of blast injury and gunshot wound deaths.

The final cluster analysis procedure undertaken was to examine clustering of the body region variables. The first analysis examined the clustering of the full data set, including the unascertained cases and those with both gunshot wounds and blast injury listed as cause of death. For the first analysis, with the entire data set, no discernible pattern was found.

Subsequent analyses were performed using the subsampling syntax. The clustering analyses found that many of the variables clustered consistently with each other. These included the vertebrae, left ribs, right ribs and the bilateral siding variables. Additionally, the neurocranium, maxillofacial and mandible variables frequently clustered together. These are shown in Figure 6-43.

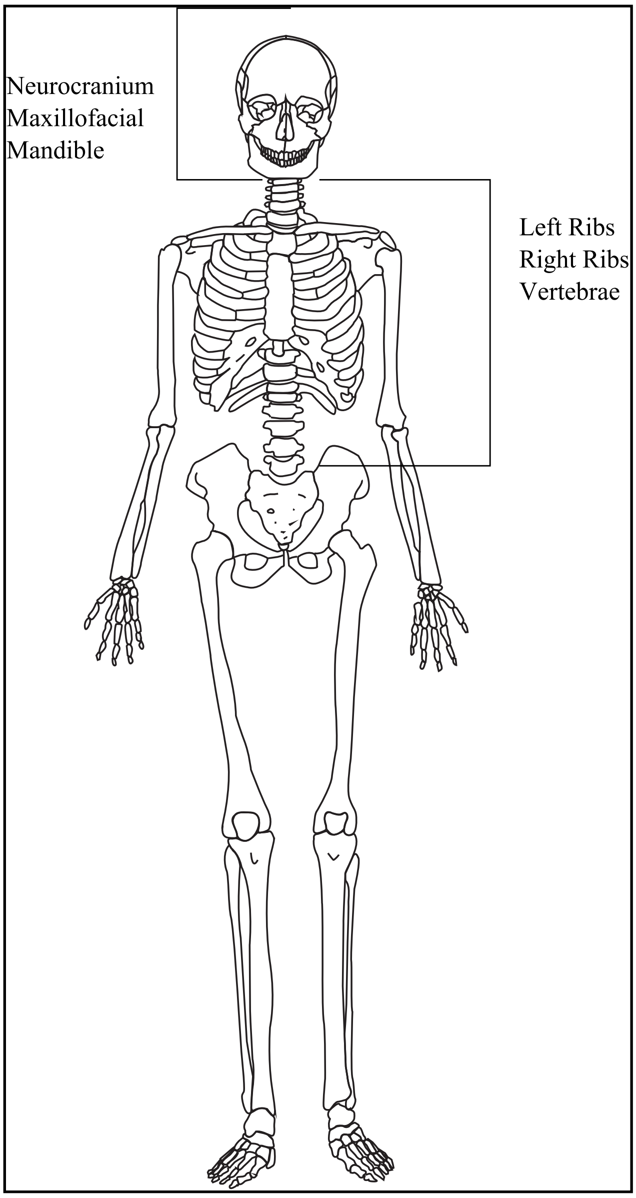

Figure 6-43: Clustering of variables in analysis of blast injury and gunshot wound injury in a sample from Bosnia. The torso variables and head variables clustered together in the analysis.

Multiple correspondence analysis

The multiple correspondence analysis identified variables which contributed most to the variance in the samples, across many runs of the analysis using a subsampling syntax. The variables identified were: neurocranium, mandible, left and right shoulder girdles, left upper arm, left ribs, left pelvis, right pelvis, right femur, left femur, maxillofacial and vertebrae. These were the variables which contributed most to the variance of the first, second and third dimensions. The first and second dimensions represent the variables which are the trunk of the body. The third dimension represents the cranial variables. This is demonstrated visually in Figure 6-44: Summary of multiple correspondence analysis using the blast injury and gunshot wound sample from Bosnia. The first and second dimension represent the torso area and the third dimension represents the head area. These were then subsequently applied to binary logistic regression to examine the predictor power of these for use in identifying and differentiating blast injury from gunshot wound cases.

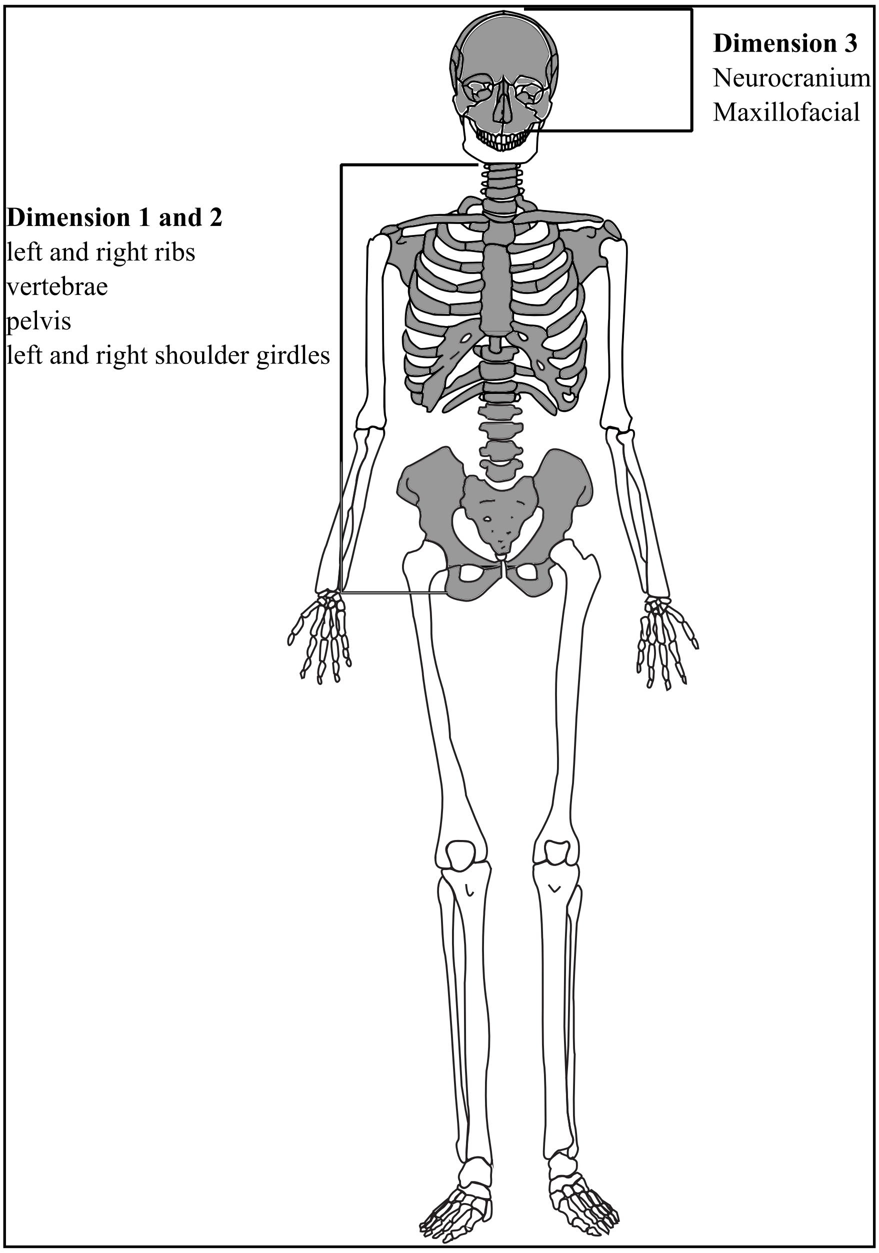

Figure 6-44: Summary of multiple correspondence analysis using the blast injury and gunshot wound sample from Bosnia. The first and second dimension represent the torso area and the third dimension represents the head area.

Binary logistic regression

Two methods of binary logistic regression were employed; the backward and the block enter methods. In the first, SPSS calculates which variables to remove from the model and produces an optimal model based on the variable statistics. In the block enter, the variables are decided by the researcher as to which to include in the model and is a process of elimination and addition through many iterations and can use variables predetermined based on hypothesis or other analyses. For the backwards method, the average Hosmer and Lemeshow's significance is 0.760, indicating good fit of the models produced. The classification percentage average is 74.86% indicating a positive increase in the classification power of the models.

In the case of the block enter method, the average Hosmer and Lemeshow's significance is 0.609, indicating good fit of the models produced. The classification percentage average is 71.62% indicating a positive increase in the classification power of the models.

It was found that there was no significant difference between the two methods; however these were produced with different body region variables. In the backward binary logistic regression, limb variables were always selected for the model, with the exception of the vertebrae in one analysis. For the block method, the researcher employed the variables identified in the multiple correspondence analysis: neurocranium, maxillofacial, mandible, left shoulder girdle, right shoulder girdle, left upper arm, left ribs, right ribs, left pelvis, right pelvis, right femur and left femur.

The interpretation of the results will be examined in the discussion chapter, relating the results to those in the clinical literature and within the context of forensic and biological anthropology.

7. Discussion

The discussion chapter is separated into sections to address the aims and objectives of the project. The first part examines the relationships and associations within the sample from the Bosnian mass graves. Section two examines the clinical literature and compares the results from the Bosnian sample analysis to these. The third section explores the methodological considerations of the research and results, addressing the strengths and weaknesses of the approaches taken and the results achieved. Section four contextualises the results within biological and forensic anthropology to address the gap in the knowledge identified in the introduction chapter.

Using a large sample of cases from the mid-nineties in Bosnia has yielded interesting results regarding the identification and differentiation of blast injury from other types of injury within the five mass graves studied. The cases from the graves were compared using various statistical methods to evaluate whether there were indicators capable of differentiating blast injury from gunshot wounds at the level of assemblages. Certain body regions were identified as being able to predict which group a case belongs to. Body regions such as the skull area, the limbs and vertebral areas differentiate between the two groups and have potential for future differentiation of trauma in large scale assemblages with suspected blast injury or gunshot trauma.

7.1. Examination of the Bosnia samples

The following section examines the similarities and differences within the samples from Bosnia, with a particular emphasis on comparing the blast injury cases and the gunshot wound cases to examine the differentiation between the two causes of death.

7.1.1. Comparing the body regions between blast injury and gunshot wound cases using Pearson's χ^2

When examining the body regions between the causes of death, certain patterns have emerged. The first method of analysis was using Pearson's χ^2 to examine statistically significant differences between prevalence of trauma to the body regions.

In the head region of the body, including the neurocranium, maxillofacial and mandibular regions, differences were seen in the prevalence of trauma with a higher prevalence seen in the gunshot wound cases. Despite the higher prevalence, these were not statistically significant differences.

Based on the knowledge that blast injury produces a diffuse pattern of injury (Hadden et al. 1978; Boffard and MacFarlane 1993; DePalma et al. 2005), it was expected to see a high proportion of trauma to this region, also particularly due to the use of rocket-propelled grenades in the sample from the Glogova graves (Wiedeman 1994; Woebkenberg et al. 2007). This type of weapon incorporates the use of an anti-tank grenade which functions similar to the hand grenade, made to fragment and cause maximum injury, which one would expect to produce a diffuse pattern of injury in the body which would consequently include the head.

For the gunshot wounds, it was expected to see a large number of cases with head trauma. The head is an area which is frequently targeted in shootings as it is a region which inflicts maximum damage (Pikus and Ball 1995; Boström and Nilsson 1999; Hsee and Civil 2008). In the context of war, expecting a high number of head wounds would be logical. Particularly in the Bosnia war context, court documentation demonstrates that many men were shot in the head (along with other possibly targeted regions such as the legs), which can be assumed to have the purpose of either disabling or killing instantly (Anon. 2000, 2010a, 2010b, 2012a, 2012b).

Additionally, a second body region, trauma to the vertebrae was found to have a high prevalence in the gunshot wound cases. This was not significantly different between the two causes of death but the difference between the two could likely again be attributed to the use of targeted shots to disable a victim. Additionally this can be an indication that this was not combat trauma as combat is undertaken predominantly in a forward facing position rather than with the combatants turned around. This is more likely to indicate either a gunshot directed specifically to the back or with the victim turned around, potentially fleeing. In the case of the blast injuries, it is also possible that the victims were turning around to protect vital organs situated at the front of the body such as the heart, stomach, intestines and others which when hit can cause catastrophic injuries with implications to life. Another consideration, which includes the head area, is protecting the head area by curling into a foetal position, likely with the back facing towards the assault, and the head tucked in for protection. Again this position is likely to incur a larger number of injuries to the back and is often found in cases of gunshot wounds with a higher prevalence of gunshots to non life threatening regions, such as the limbs (Aderounmu et al. 2003; Cowey et al. 2004; Dougherty et al. 2009; Akhator 2010).

Left forearm trauma was identified as being significantly different in its prevalence between the blast injury cases and the gunshot wound cases. In this case, 35.4% of the blast injury cases were found to have left forearm trauma, with 6.1% in the gunshot wound sample. For this body region, the trauma was present 5.8 times more often in the blast injury group. This is linked to the diffuse way in which explosives injure by aiming to cause as much trauma as possible over a large area. This is also a difference in the specific aim of hitting vital areas, with gunshot use being targeted to certain areas rather than in blast injury where the spread of explosive materials is not controlled by the perpetrator and leads to a diffuse pattern of injury (Hadden et al. 1978; Boffard and MacFarlane 1993; DePalma et al. 2005).

For the inferior portion of the skeleton, presence of trauma to the left femur was significantly different between the causes of death. In this case, the blast injury causes of death had more cases of left femur trauma, consistent with the literature indicating a high prevalence of trauma to lower limbs in cases of blast injury in the majority of contexts, as opposed to gunshot cases. The number of left femur trauma in the gunshot cases is surprisingly low with only 67 in a sample of 443. This is likely to be explained by the choice of body region made to inflict most damage and lethality rather than injury, whereas blast produces a diffuse pattern of damage because of shrapnel ballistics and is more likely to affect soft tissues.

The left tibia and fibula did not exhibit a difference between the two causes of death, which is interesting due to the close proximity of this body region to that of the left femur, which is significantly different in blast injury cases. This may be related to the biomechanics of these bones, with testing having shown that the tibia is more resistant to forces than the femur (Evans and Bang 1967). Based on shrapnel ballistics it can be assumed that the left tibia and fibula would be likely to be affected by blast injury; however this is not the case. In the sample from the Kravica warehouse, the choice of rocket propelled grenade indicates that the launching of this weapon was likely to result in a targeting towards the general position of the upper body, as demonstrated by the entry points through windows and doors and the impact points waist-level and up that were found on the back wall of the warehouse found with human tissue embedded (Headley 2001).

In both the blast injury and gunshot wound groups, foot trauma on both the left and right was rare. This is not an unexpected finding as the prevalence of foot trauma is rare in shootings and found predominantly in landmine injuries (Jacobs 1991; McGrath 2000; Meade and Mirocha 2000; Khan et al. 2002; Bilukha 2006; Bilukha 2007, 2008; Soroush et al. 2008), albeit can be encountered when looking to disable the victim. Additionally, in blast injury cases, foot trauma is predominantly associated with land mine incidents in civilians or in under-vehicle IED explosions in combat contexts (Bir et al. 2008; McKay and Bir 2009; Ramasamy et al. 2011; Ramasamy et al. Ca.2009).

Conversely, body regions which were not significantly different between the causes of death were also observed. With patterns of injury in blast scenarios having a high prevalence of extremity injury it was expected to see a difference here in comparison to the gunshot wound cases. However, this was not the case (apart from the left femur). It is believed that the high prevalence of trauma to the femur is a reflection of the use of rocket-propelled grenades in the Bosnia cases of blast injury. Particularly the weapon was aimed at a torso height, which could have caused damage to associated areas such as the upper portion of the lower limb.

Significant differences in the prevalence of neurocranium trauma were expected. With a large number of victims with gunshot wounds as the cause of death, a significant difference between the blast injury and gunshot causes of death was expected, potentially due to specific targeting of this body area in the case of the latter. This was not seen. A potential explanation for this difference could be the lack of specific targeting of the cranial area with a goal of rather disabling the person by shooting them in the back, however this is speculation. Trauma to the vertebrae was present in 192 cases, confirming this however without significant difference between the two (with only a small prevalence difference of 8.8%).

No difference was found in the torso area, the left and right ribs, as was expected, particularly associated with the vertebral trauma in the gunshot cases. The difference between the two causes of death was quite small on both the left and right sides, with only 5% and 6.3% prevalence difference, respectively. Interestingly, despite the larger prevalence of trauma to the vertebrae in the gunshot wound cases, trauma to the rib body regions were more common in the blast injury cases. This is a reflection of the diffuse nature of the fragmentation of a grenade, aiming for maximum spread of the grenade contents.

In the comparison of the two causes of death, the siding variables were examined to note any differences in the pattern and prevalence of the injuries. No difference was found between the left and right, but bilateral trauma was significantly more common in the blast injury cases from those with gunshot wounds. This fits with the clinical literature results which indicate no side preference in blast injury, due to the nature of ballistics of explosives which are not targeted but aimed at reaching maximum coverage of the body at once. Trauma to the unsided regions of the body was significantly more prevalent in gunshot wound cases. This is due to higher prevalence of vertebral, neurocranium, maxillofacial and mandible trauma in the gunshot cause of death group.

7.1.2. **Clustering within causes of death**

Clustering of the blast injury and gunshot wound samples was performed to examine any patterns within each of the cause of death samples.

7.1.3. **Blast injury**

The blast injury cases were analysed using binary clustering and yields a two cluster solution according to the agglomeration schedule. With this solution, all cases were grouped into one large cluster and two cases were clustered in the second.

The cases which clustered separately from the large cluster were examined to interpret why these cases were different. The first case (GL01/375B) was a case from the Glogova 1 mass grave. This was a complete body with trauma to the neurocranium, maxillofacial, mandible, left shoulder girdle, left upper arm, left forearm, left hand and left ribs. The second case (GL01/541B), also from the Glogova 1 grave and a complete body, had trauma on the neurocranium, maxillofacial region, vertebrae, left shoulder, left upper arm, left forearm, left pelvis, left femur and right tibia and fibula.

Comparing these two cases to the others in the data set used for clustering, it is noticeable that these have trauma in areas which are not commonly seen in the other cases. For the first cluster, maxillofacial and mandibular trauma is only seen in 26.1% and 17.4% of the cases, respectively. Additionally, in the case of GL01/541B, vertebral trauma was also noted, again something found to be infrequent in the first cluster. In the previous analysis using Pearson's χ^2 this variable was significantly associated with gunshot wound causes of death rather than blast. In case GL01/541B, the left pelvis and right tibia and fibula had trauma, variables which had a low prevalence with the blast injury (23.9% and 21.7%, respectively). These cases are also seen as grouping together in further analyses when subsampled and examined with the gunshot wound cases, indicating possible outliers.

For the first cluster, no apparent patterns were discerned when grouping the cases according to the agglomeration schedule. Without using the agglomeration schedule to quantify mathematically the difference between the clusters results in more clustering within the first group. Six clusters appear visually with a seventh including the two cases previously identified. Returning to re-examine the agglomeration schedule, there is a larger gap between a six and seven cluster solution than most, except the two cluster solution. This highlights that this method may not be ideal if using the agglomeration schedule as the sole criterion for determining the number of clusters in the solution. Matters are confused further when examining where the cluster separations are according to the cluster membership table, which calculates this mathematically. In this case, the separations were not at the visually identified points and it was deemed it best to examine the frequencies of the variables for each cluster as it was assigned mathematically for patterning rather than visually in an effort to maintain statistical accuracy. Cluster 3 and 5 had trauma to the neurocranium, maxillofacial region, mandible, vertebrae, left shoulder girdle, left upper arm, left forearm and left hand. Additional variables were split between the two groups but the left side of the body clustered together, pointing at a body positioning difference when the explosives impacted the victims.

Cluster one has a high prevalence of torso trauma, with trauma to the vertebrae, right shoulder girdle and left ribs present in many cases. Lower limb trauma was not seen in prevalence higher than 20% of the cluster (left tibia and fibula). This corresponds to the dead having been struck by the grenade blasts in the torso area, possibly the lower torso due to some involvement of the pelvic area. For cluster two, the prevalence of trauma to the skull area is high, with the neurocranium being affected 58.3% of the time, a figure more associated with the gunshot wound pattern of injury. This could reflect a different positioning within the Kravica warehouse during the attack, for example being closer to the front of the warehouse where the RPGs were entering, before their velocity dropped and gravity would bring them down. The fourth cluster had a high prevalence of trauma to the left ribs, pelvis, and both femurs. This small group of four cases exhibits a more typically diffuse and bilateral pattern of trauma, along with the high prevalence of lower limb injury. However, this lower limb injury is highly prevalent (50% or more) in both femurs, however not in the tibia or fibula. This demonstrates that for cluster 4, the point of impact for the explosive munitions was towards the middle of the body, diffuse and bilateral. This group's pattern is typical of most patterns of injury in civilian bomb blast and different than that found in the gunshot wound group and in the literature on gunshot deaths. Cluster 6 was a sole case whose trauma occurred on the right side of the body making this case unique when comparing to the others. Cluster 7 are the two cases previously identified (GL01/541B and GL01/375B), once again standing out from all other cases and having lower limb trauma which includes the tibia and fibula, on both sides, which is contrary to the other clusters, an indication of differing position at death from some of the other groups, potentially further away from the original point of entry. This however may not be the case as points of impact on the back wall of the warehouse were clearly found in the forensic investigations and were located at torso and head height (Headley 2001).

7.1.4. Gunshot wound cases

The large size of this sample clearly exemplifies the difficulty in assessing a dendrogram of this size, particularly where the difference between the groupings can be very small, when the distances are scaled by SPSS. The distance between the consecutive vertical bars can be difficult to interpret when there are a very large number of cases and in this case visual confirmation of the solution was near impossible. Relying on the agglomeration schedule becomes the only option in a sample of this size, leading the current researcher to conclude that cluster analysis is best suited to smaller samples. Based on cluster membership output, the cases which stand out as being different from cluster 1 are from the Ravnice grave, one from Lazete and a sole case from Glogova 1. For the second cluster, trauma to the neurocranium, maxillofacial, mandible and vertebrae are prevalent. Right femur and left tibia and fibula were also found in 2 of the 3 cases.

The third cluster had a high prevalence of trauma to the neurocranium and all cases had vertebral trauma. Right shoulder and left upper arm trauma was also prevalent as well as the right ribs and pelvis. For these cases, trauma in the left and right femurs was noted in all five cases, as well as commonly in both side tibiae and fibulae. The fourth cluster was a single case with trauma to the neurocranium, maxillofacial, left shoulder, right forearm, left and right hands, right ribs, left and right pelvis, left femur. For all four of the clusters, trauma was bilateral.

Examining the clusters and their cases does not yield a pattern which is different from those in cluster 1. There is however, a predominant prevalence of trauma to the skull area could potentially indicate specific targeting to this area, as previously discussed in 7.1.1.

7.1.5. Using cluster analysis to differentiate between blast injury and gunshot wound causes of death

The purpose of this part of the analysis was to determine if this statistical method finds a difference between the groups and accurately places the cases into separate clusters. The optimal cluster solution number varied between 2 and 5 clusters, with the 2 cluster solution being the most common. Examining these clusters does not show differentiation between the two samples. In the analyses which have more than 2 clusters in the solution, the groupings identified cases which were different from the others. As previously seen in the blast injury cluster analysis, the cases GL01/375B and GL01/541B have appeared in distinct clusters either together or with other cases.

For the analyses yielding solutions with more than two clusters, none of the solutions indicate proper differentiation. Most of the clusters include both causes of death and are usually comprised of only a small number of cases. The cluster including the majority of cases includes both. It is concluded that this technique does not differentiate well between the gunshot wound and blast injury causes of death. Using this technique to recognise and separate cases between the causes of death is unlikely to yield good results as demonstrated over multiple analyses which did not point to a distinct pattern between the two. This could point to a similarity between the two groups, however this is not likely as there is demonstrated statistical differences between the two when applying other statistical methods. It is concluded that the choice of method was inappropriate to differentiate any differences in the patterns between the two causes of death.

7.1.6. Clustering body region variables- blast injury and gunshot wound deaths

Moving beyond comparison of cases, cluster analysis can be used to compare variables to examine patterning within these. The analysis using subsampling syntax was performed ten times to determine if there was a patterning within the variables.

The variables of vertebrae, left ribs, right ribs and bilateral siding clustered together during the analysis. This is likely related to their close proximity in the body and likelihood that when trauma is present in one region there is associated trauma in a nearby body region. This is particularly likely with the blast injury cases as the pattern in these situations tends toward a diffuse spread of trauma and is likely to indicate associated body region variables would have trauma present. Three other variables also clustered together frequently, the neurocranium, maxillofacial and mandible body regions. Again, this is due to close proximity in the body and occurring in the small areas associated closely together. Additionally, the gunshot wound cases which exhibit trauma to this region also have more than one area of injury at once. This is seen in cases which demonstrate entrance wounds to the back of the head and associated maxillofacial trauma or mandibular trauma due to the exit wound. As such, it is not unexpected that for this body region, the three variables cluster closely. When performing the analysis including the siding variables, the bilateral siding variable was the only one which seemed to differ from the others. Additionally, this variable clustered predominantly with the vertebrae, left ribs and right ribs variables. This is to be expected with the blast injury cases and their more diffuse pattern. Examining the prevalence of the left and right ribs, these were more associated with blast injury cases and as such more likely to show a bilateral siding pattern for the trauma due to typical diffuse patterning in these cases. Conversely, vertebrae trauma was found in a higher number of cases of gunshot wound deaths (N= 192). As such bilateral siding seems to be associated with the three variables and both with the gunshot and blast injury causes of death.

Overall, using cluster analysis did not yield differentiation between the two causes of death. It has however shown that there are variables which associate closely together which could potentially be employed in further statistical testing (which will be explored with multiple correspondence analysis and binary logistic regression).

7.1.7. Multiple correspondence analysis of blast injury and gunshot wound cases

Multiple corresonpondence analysis was used to identify variables which contributed to the variance of the samples and which differentiated between the two causes of death in graphical examination of clouds of cases. These variables serve as potential indicators which can differentiate between the two types of trauma examined in these samples. This part of the analysis was undertaken using syntax to randomly subsample from the blast injury and gunshot wound cases. Interpretation of the results is based on the object points labelled by cause of death and by examining the discrimination measures across three dimensions to see which account for most variance in the dimensions, and the patterns in the data. Across three dimensions, between 34% and 36% of the variance is explained.

The results of the analyses varied slightly over the course of six repeated analyses. This is likely due to the subsampling that was undertaken to ensure that the samples for each of the two causes of death were of approximately the same size. This can have impacted on the results, potentially yielding results which were different if the composition of the samples was vastly different. Performing the analysis multiple times was used to counter this effect and to ensure accuracy of the results.

To assess which variables would discriminate between the causes of death, the object points labelled by cause of death were examined. Identifying which dimensions had the best discrimination potential, the associated body region variables were identified. Over the six analyses, the dimensions which consistently showed best discrimination between the causes of death were the first and third dimensions, indicated by a visual separation of the cases across the axes of these dimensions. Although differentiation between the causes of death weren't always distinct, there were emerging patterns on the extremes of each of the dimensions with some overlap in the middle of the clouds. This is likely due to the percentage of variance within the dimensions explained, which ranged from 34% to 36%, which is not a large number but still accounts for some of the differences within the sample and inferences can be made which can contribute to subsequent analysis phases.

The variables which are noted as having contributed most to the variance of dimension 1 are noted in Table 6-49. Dimension 1 represents the trunk area, with the rib, pelvic, vertebral and shoulder girdle variable being important in the differentiation of the causes of death in the analysis. In the case of the left ribs and left upper arm, it was found that these differentiate on dimension 1 in but was associated with this dimension in samples which did not show great differentiation between the two causes of death. As such, this weakly associated with the causes of death. Right ribs contributed as well to variance on dimension 1 in many of the analyses, but also contribute to dimension two simultaneously. As such, the discriminating effect of this variable is weakened because of this and may not be as accurate at separating the two causes of death. The left and right pelvis discriminated very well on dimension one, with no concurrent contribution to the other two dimensions. Examining the prevalence for these variables, it is seen that this is higher in the blast injury cases which could indicate that these variables can discriminate between the two causes of death. This result follows previous clinical conclusions related to the diffuse nature and characteristic of blast trauma which contrasts with the gunshot wound cases in the Bosnia sample which had higher prevalence of injury to body areas with more vital organs such as the head region.

The skull region variables were strongly associated with the first dimension and in these cases had little contribution to the second dimension. Additionally, these were found as contributing highly to the variance in comparisons of dimensions 1 and 3, where both the dimensions separate the causes of death adequately. Referring back to the previous analyses using Pearson's χ^2 these variables were seen in high prevalence in the gunshot wound cases, although not significantly once the Holm-Bonferroni correction was applied.

Examining the cluster analysis of the body region variables, these clustered together. This can be explained by the close bodily proximity and association of gunshots specifically aimed at the head region with possible intention to inflict maximum damage. This demonstrates that solely using multiple pairwise χ^2 would have no identified these significant differences and using a multivariate statistical approach was better suited to identifying important associations between the variables.

Examining body region variables which associate with dimension 3, the skull region variables demonstrate good discrimination and association with each other. The left arm variables were also found to discriminate on dimension 3, particularly the left upper arm. Examining the prevalence of this variable it is associated with frequency in the blast injury cases. Using the Pearson's χ^2 this variable was significant before Holm-Bonferroni correction. The frequency in the blast cases is double that of the gunshot wound cases and is a good discrimination measure in the multiple correspondence analysis, indicating a potential indicator to differentiate between the two causes of death. This will be further applied in the next section. Additionally, in both the first and third dimensions, many of the variables found were related to the extremities (Hadden et al. 1978; Rignault and Deligny 1989; Boffard and MacFarlane 1993; Hayda et al. 2004; Martí et al. 2006). This is in keeping with the literature which indicates prevalence of extremity trauma associated with blast injury contexts. These were also identified in the cluster analysis, but the multiple correspondence can aid in visually assessing the discrimination power and association of the variables by also examining the object points and the associated clouds which demonstrates how much overlap there is in the causes of death and give an indication of how much the associated variables differentiate the two groups. In this analysis, the dimensions which differentiate between the two causes of death were dimensions 1 and 3. Dimension 1 represents the torso area and dimension 3 the cranial area. These variable groups discriminate well between the two causes of death and serve as an indicator of the areas where the patterns of injury between the blast injury and gunshot wound cases differ.

Subsequently, these variables are applied in a binary logistic model to test their potential as indicators of blast injury, which will be examined in the following section.

7.1.8. Binary logistic regression

Binary logistic regression was employed to test the indicators identified in the multivariate graphical methods of cluster analysis and multiple correspondence analysis to differentiate between blast injury and gunshot wound cases.

Binary logistic regression- backward stepwise method

Using the backward stepwise method of logistic regression in SPSS 19.0, the analysis was repeated five times and had differing results for each analysis. The analysis was repeated five times to ensure that the subsampling could provide a randomised sample of the gunshot wound cases, as the number of cases was much higher than the blast injury ones. This is likely due to the composition of the sample, which is randomly chosen and varies from analysis to analysis. Employing this method yielded accurate classification ranging from 67.8% to 81.6% and the Hosmer and Lemeshow's R^2 value from 0.529 to 1.000. Examining the variables which SPSS chose for each model helped to identify which model was likely to be the best by looking at the significance value of the Wald statistic. One particular analysis, the fourth had all variables with a significant *p* value, meaning that these predictors contribute significantly to predicting the outcome (cause of death). The variables included in the model were the vertebrae, right shoulder girdle, left forearm and left femur.

In this model the Hosmer and Lemeshow's R^2 is 1.000, indicating that this set of predictor variables predict the outcome perfectly. To interpret the model, examination of the Exp(B) value gives odds ratios which are very useful. For the vertebrae variable, Exp(B) = 0.215 which indicates that given the absence of trauma to the vertebrae, the odds that this is a case of gunshot wound death decrease. Conversely, presence of trauma in the other three variables increases in odds of the outcome being blast injury based on the pattern. To predict the probability of the case being a gunshot wound related death, for this model, the skeletonised remains examined would exhibit a wound to the vertebrae but none to the limb variables which are examined in the model (right shoulder girdle, left forearm, left femur).

Examining the third analysis yields similar results with the exception of the omission of the vertebrae variable. In this case, the classification accuracy is of 73.7% with a Hosmer and Lemeshow's statistic of 0.907. For this analysis, three variables are included in the model, the right shoulder, the left forearm and left femur. This is similar to the previous model. For the right shoulder, if no trauma is seen, it is 3.587 times more likely to be a case of gunshot wound related death. For the left forearm and the left femur variables, the odds ratios are, respectively, 9.635 and 12.118. Trauma seen in these body regions indicates blast injury rather than gunshot wound deaths.

Both these binary logistic analyses using the backward stepwise method yield a suitable model with correct classification over 71%, indicating that extremity variables are significant in predicting the type of trauma. Particularly, presence of trauma to the right shoulder, left forearm and left femur variables indicate probability of the presence of blast injury related death.

Binary logistic regression- block enter method

Comparatively to the backwards step method, indicators can be chosen by the researcher to include in the model. The indicators can be chosen based on research questions or previous analysis. Using the multiple correspondence analysis previously undertaken, variables contributing to the variance in the samples were identified and tested as predictors of blast injury in the samples. Five analyses were conducted using these indicators and yielded varying results. Despite employing the same indicators every time, it is likely that variation in the Hosmer and Lemeshow's goodness-of-fit statistic and classification accuracy was due to subsampling which produced a sample using different cases for each of the analyses. This methodology was compared with the previous binary logistic procedure to determine if it is best to choose the indicators in this case using multiple statistical tests or to simply employ the statistical software to determine the most accurate indicators (see 0).

Goodness-of-fit was evaluated with the Hosmer and Lemeshow's statistic and the best model was found to be from analysis #4, which had 70.2% classification accuracy. The body region variables which were identified as significantly contributing to the model were the right shoulder girdle, the right pelvis and the left femur.

When trauma to the right shoulder girdle was present, this indicated an increase in the probability of the case being blast injury. The Exp(B) value indicates that the presence of trauma to the right shoulder girdle increases the odds of the case being blast injury 7.35 times. For the right pelvis, presence of trauma indicates an increase of 4.13 times in the probability of the trauma being blast injury. The left femur body region variable was associated with an Exp(B) value of 0.170, again indicating that when the outcome of the variable changes from presence to absence, the odds of the trauma being blast injury decreases. In fact, when trauma is present in the left femur, the odds of blast injury increase 5.88 times.

The next best model found was the one from analysis #3, which had 70% classification accuracy and a Hosmer and Lemeshow's R^2 value of 0.626. For this analysis, two of the entered variables were found to significantly contribute to the model, the left femur and vertebrae. For the left femur, the Exp(B) value was 0.186, indicating that when the predictor outcome reaches a value of 1 (or absence), there is a decrease in the odds of the trauma being blast injury (thusly indicating potential gunshot wound related trauma). This indicates a 5.38 times increase in the odds of having blast injury when trauma to the left femur was present. For the vertebrae variable, the Exp(B) value is 2.565, indicating that absence of trauma to the vertebrae corresponds to an increase in the odds of blast injury trauma being identified. This can conclude that presence of vertebral trauma is associated with gunshot wound cases.

Comparing the backwards stepwise method and block enter method

As both methods of building the predictive model were investigated, the results of these were compared to note any differences in the outcome over five analyses. No significant differences were found. For this type of statistical application, the difference between the two would lie in the previous assumptions of the researcher. In the context of this research, the previous assumptions came in the form of exploratory statistical testing using cluster analysis and multiple correspondence analysis to examine any patterns in the data. Testing the predictor variables identified in the multiple correspondence analysis yielded similar results to that accomplished by using a backwards stepwise method built into SPSS 19.0.

Classification percentage was found to be higher using the backwards stepwise method but not significantly so.

Comparing the variables which were identified in the backwards stepwise method, these were similar to those employed in the block enter method, having been previously identified in the multiple correspondence. The sole difference was the inclusion of the skull region variables in the block enter model however these were not shown to significantly influence the model. Only once did a skull region variable influence a block enter model and this was in the analysis with the lowest Hosmer and Lemeshow's goodness-of-fit statistic. Aside from this, the variables which were predominantly selected by SPSS in the stepwise method and those which contributed significantly in the block enter model were extremity variables. This is in line with the literature regarding blast injury patterns which indicates a predominance of extremity injury in blast contexts. This is also converse to the pattern found in the gunshot wounds in the Bosnia sample, which had a higher prevalence in maxillofacial, mandible and vertebrae body regions.

Cross-validation

Cross-validation of the studies could not be undertaken presently as the availability of another sample could not be determined during the time of the research. Samples of known blast injury in skeletal assemblages are few and far between and the current sample appears to be the only one which could be made available for research during this time period.

Verification of the results from the statistical analysis will be a subsequent area of research once a suitable sample can be located. Replication of the methodology and predictors of blast injury will be undertaken.

7.2. Applicability of the statistical methods for differentiation of trauma in large scale assemblages

One of the aims of this research is to explore the application of multivariate statistical methods to large scale assemblages, as seen in the Bosnia samples. The purpose of these tests was to examine any patterns and the results of these for comparison to previously established knowledge which was located in the clinical literature. Additionally, these tests were employed together to identify the patterns within the data and discover any differences between the location of trauma for the blast injury and gunshot wound causes of death. The purpose was to create a full complement of analytical methods which examine the assemblages as a whole rather than at the individual level.

The first analysis of the samples involved using Pearson's χ^2 to compare the prevalence of trauma to the body regions, comparing between blast injury cases and gunshot wound cases. Differences in the prevalence of trauma in various body regions were identified however, pairwise testing with this method proved problematic when used consecutively due to the need for a correction which affected the amount of tests being significant. This can mean that differences in the variables can be missed, particularly if there is an interaction of multiple variables which show a difference between the groups. Patterns within the data which can contextualise the finds cannot be seen by individual pairwise testing. Trauma analysis in large assemblages may require analysis of interactions to uncover patterns leading to identification of trauma.

The cluster analysis demonstrated some patterns within the data but it was found that the most useful analysis was undertaking the clustering of the body region variables which permitted to demonstrate which of the variables clustered together and could potentially serve as a way of differentiating between groups. Particularly, the skull region variables were found to cluster together which is likely a reflection of proximity of these within the body. This also indicates that the pattern of injury found in these body regions differs from those found in the other body regions enough to stand out in the visual assessment and could indicate differences which can be used for the identification of trauma. Torso variables clustered together as well, a reflection of proximity of these body regions to each other. The most striking result from the cluster analysis of the body region variables was the consistent separation of the bilateral siding variable from the others, indicating a large difference was found. Examining the prevalence of bilateral trauma in the blast injury sample, it was found to consistently be higher than in the gunshot group. This supports the literature and the conclusion that bilateral trauma is more likely to indicate blast injury in a questioned sample.

Examining the individual causes of death, or the combination of the blast injury and gunshot wound, did not yield any distinct patterns within the data. Ideally, a distinction between blast and gunshot wound trauma was sought to demonstrate the difference between the two. Visually, no immediate distinction was found, not necessarily indicating that there are no differences between the cases but potentially indicating that using cluster analysis was not suitable to analyse the differences. Representing the cases using vector geometry may not take into account the subtle differences existing or may need additional processing or combination with other techniques.

The use of multiple correspondence analysis in the context of the Bosnia samples proved to contribute valuable conclusions regarding the body region variables with large influence on the patterns in the samples. This method of exploratory analysis of samples can be of use in the analysis of large scale assemblages of skeletonised remains which need contextualising, due to the use of multiple variables at once which can take into account interactions between these. Examining individual sets of remains rather than a whole assemblage is of particular concern in contexts such as human rights investigations. By employing these exploratory methods with the samples from Bosnia, distinctions were identified between groups. Trauma to the individual is of value but it is the group which is likely to give insight into the nature of the trauma. Finding uniform trauma patterns within the graves lends confidence to the conclusions that they were all killed similarly, strengthening the argument about the nature of the trauma and potential human rights violations. Examining prevalence of trauma within these groups can help explain what occurred at the group level, which is often overlooked in favour of examining trauma at the individual level. In this research, examining the question of whether or not combat is at the source of the injury patterns is important, due to consistent questioning of this in current court cases (ICTY 2010a,ICTY 2010b,ICTY 2012a,ICTY 2012b). Conclusions can be explored and inferences made using the examination of one set of skeletonised remains however, examining the whole of the assemblage will strengthen the conclusions and particularly so when employing statistical methods which can serve to quantify associations, patterns, similarities and differences within groups and between groups.

In the examination of the results from the multiple correspondence analysis, quantification of the variables which had been identified in the discrimination measures was sought. At this point, pairwise Pearson's χ^2 tests had already been performed and highlighted statistically significant differences in the variables of interest when re-examining the Pearson's χ^2 . Problematically, statistical significance had to be ruled out in many of the tests due to the employ of pairwise testing which necessitated the application of Holm-Bonferroni corrections. The variables which were significant and remained significant following correction were the left forearm, left femur, bilateral siding, and unsided variables. Referring to Table 6-49, it is seen that many more variables were identified as discrimination measures in the analyses. Particularly, those found to contribute most variance on Dimensions 1 and 3 include variables which were not found to be significantly different when using pairwise Pearson's χ^2.

Pairwise variable testing subsequent to multiple correspondence analysis could be an alternative to examine significance between the variables indentified in the discrimination measures. Returning to the results of the pairwise Pearson's χ^2 tests, we see that some of the variables identified in the discrimination measures portion of the multiple correspondence analysis would have significant differences between the two causes of death, likely contributing to the dimension variances. Additionally, part of correspondence analysis methodology employs the χ^2 statistic, without having to employ consecutive pairwise testing. It is concluded that using the Pearson's χ^2 statistical test in combination with multiple correspondence analysis is useful for exploring the strength of the associations or differences between the groups once identified in the discrimination measures portion of the analysis, rather than employing this technique on its own or before other statistical analyses, as demonstrated in this work.

The last statistical technique employed was binary logistic regression. This was utilised to explore the possibility of a predictive model to identify trauma within the Bosnia sample and which could potentially be applied to future analysis. Using SPSS 19.0 permits the researcher a variety of approaches to build the final model, and comparing these two in section 6.5.3 yielded similar results for the two final models. The binary logistic regression models clearly indicated that trauma to the limbs was associated with blast injury and that these predict a probability of classification in the blast injury trauma group over the gunshot wound trauma group. Again, referring back to the tests made in the Pearson's χ^2 analysis, the variables significantly contributing to the backwards stepwise model were found to be different to those identified as significantly different in the pairwise Pearson's χ^2. Solely using the variables identified in the Pearson's χ^2 test to attempt to identify blast injury in an assemblage would yield inaccurate results and would not be suitable to attempt this. It is concluded that employing the pairwise Pearson's $\chi^2$is inappropriate due to the need for a correction factor which then prevents significance from being identified due to the overly conservative α-level.

These results can serve to further analyse cases from the same conflict, particularly the cases with which there may have been some argument as to the final nature of the trauma. Strictly assessing the application of this technique for this research, the author believes that its results are useful and have potential for further use and with other assemblages for the analysis and prediction of group classification.

7.3. Comparison of Bosnia sample with previously published literature

An important aim of the current research is to establish whether the patterns of injury in the Bosnia sample are the same or differ from those in previously published literature, particularly to address any questions regarding the nature of the trauma in the sample. The main objective is to identify any similarity or differences in the patterns of the Bosnian sample and those found in various blast situations, particularly those related to combat. This seeks to address whether or not the injuries seen in the Kravica warehouse victims were related to combat. Furthermore, comparisons are made with the patterns of injury from differing contexts, seeking to identify similarities and differences which can aid in the identification of blast injury in skeletal assemblages in future.

To compare and contrast claims made in published literature with observations derived from the current project, it was necessary to re-code the data to ensure the body regions corresponded to the same as those found in the literature. It was found that the literature contained less specific data, with the prevalence reported for larger body regions. This represents one of the difficulties in using the medical literature, which focuses on soft tissue and body systems, such as the nervous system, musculoskeletal system, respiratory system and nervous system. This creates issues when wanting to compare the much more detailed level of data from the Bosnia sample and that which is published in the clinical literature. This is a reflection of the purpose of the clinical literature and its aims of medical management dissemination and focus on the likely more life threatening injuries to soft tissue which predominate in blast injuries (Bowyer 1996; Rowley 1996; Horrocks 2001; Almogy et al. 2005; Avidan et al. 2005; Çeliköz et al. 2005; Ad-El et al. 2006; Shuker 2006; Ezzedien Rabie 2008). Data which were used to compare to the patterns of injury in the Bosnia sample were easily identified, whether this was looking at specific skeletal injury or the pattern data which indicated the general areas of injury and noted skeletal involvement along with soft tissue trauma (only skeletal trauma was compiled and employed). Employing the data which included soft tissue trauma posed its own limitations and may affect the interpretation of the results but the author believes that this prevalence data still holds value in identifying the patterns and comparing those seen in strictly skeletal remains, if the relevant skeletal trauma information can be extracted clearly from the work.

7.3.1. **Combat**

A recurring question during the International Criminal Tribunal for the Former Yugoslavia is the nature of the trauma in the cases from the Kravica Warehouse. The nature of the trauma, blast injury, is not disputed however the way in which this trauma was inflicted has been questioned(ICTY. 2010a, ICTY 2010b, ICTY 2012a, ICTY 2012b). Whether the injuries were sustained during combat is the main issue which has been raised and one of the objectives of this research was to examine any possible similarities between the patterns of injury in the Bosnia sample and those found in combat contexts.

Along with examining the questions which have been raised at the International Criminal Tribunal for the Former Yugoslavia, comparisons to known patterns of injury from various contexts can serve as useful information for analysis of skeletal remains. With the increasing involvement of anthropologist in cases of blast, this information can serve to inform the contextualising of trauma in individuals or an assemblage.

World War One and Vietnam

The rationale behind using data from World War One was to attempt to replicate some of the factors which are at play in the Bosnia sample. In the World War One sample, the men were not using body armour which is in consistent use in modern combat. By using the cases from World War One, this replicates the type of clothing which the skeletons in the Bosnia mass graves were found wearing, which did not include any indication of any personal protective armour (Chartrand and Embleton 2007). An important difference between the Kravica warehouse sample and the World War One cases may be the protective effect of trenches in latter. However, this was countered by using cases which were both from trenches and open-air casualties. Additionally, similarities in the protective effect of the trench may have been replicated by the walls of the warehouse. Despite this, differences in the pattern may be attributed to the protective effect of the trench in those cases, but this was deemed to be negligible, due to the care taken to have a wide type of cases in the sample and its large size.

Five body regions were found to exhibit significant differences between the samples. The vertebral region is important, with the Bosnia cases having vertebral trauma in more than two times the cases in the World War One sample. It is unlikely that vertebral trauma is an indication of combat related blast trauma as combat is usually undertaken in a forward facing position, towards the enemy. It can be assumed that turning the back towards is a protective mechanism, to ensure safety to the front of the body containing vital organs.

In the World War One sample, cases were predominantly of deaths from the infantry and often involved those killed in the trenches by mortars. It was found that in the upper limb comparison, the Bosnia cases had 3 times the trauma found in the World War One Sample. In the pelvis, there was 5.8 times more trauma in the Bosnia sample and twice the amount of trauma in the lower limbs. The likely distinction causing the difference can be the protective aspect of trench warfare.

In examining the data from Vietnam, all body regions analysed were significantly different to the trauma patterns in the Bosnia cases. Again, as in the World War One sample, this data was selected to replicate clothing conditions. Additionally, trauma in Vietnam was predominantly of the gunshot wound nature, with the increase in the use of explosives seen in later modern combat, such as the Gulf Wars. This is likely the source of the differences in the prevalence of trauma.

Northern Ireland, Iraq and Iran, Lebanon

Examining these three conflicts, areas which were significant different between these and the Bosnian sample were identified. The head and neck and thorax and back regions were examined. Particularly in Northern Ireland, these were areas which would have been protected in the troops and consequently much more trauma was seen in the Bosnia sample in these regions.

In Lebanon, all examined variables were found to be significantly different with a much higher prevalence of trauma in all body regions except for the torso. Interestingly, torso trauma was nearly twice as prevalent in Lebanon. The high prevalence to all other body regions is a distinct reflection of the nature of blast injury and its diffuse pattern of injury. Mandibular trauma was also high in the Iraq and Iran sample, more than twice as much trauma than in the Bosnia cases. A likely explanation for this high prevalence in that portion of the head would be the use of helmets in the troops, which were not found with the Bosnian skeletons. This leaves the mandibular area exposed and vulnerable, highlighting an important consideration for head protection in future, although this is changing recently (Breeze et al. 2010; Zachar et al. 2013).

Modern conflict

Cases from the first Gulf War, Operation Iraqi Freedom (OIF) and Afghanistan were examined to compare to the Bosnia data. Comparing the data in Ramasamy *et al*'s (2009) article on the Gulf War with the data yielded a significant difference between the two for all the variables. In the comparison of Operation Iraqi Freedom data, chest and back along with the lower limb were significantly different. The Afghanistan comparison yielded significant differences in the prevalence of foot and femoral trauma. This shows a statistically demonstrated difference in the patterns of injury, which distinctly identifies that the Bosnia trauma is not like the trauma found in modern conflict. Particularly in the

Gulf war, no similarities were identified. In the OIF data, it is particularly important to note that trauma to the chest and back is much higher in the Bosnia data than in the OIF sample, clearly indicating that body armour plays a big role in the differentiation of the pattern between Bosnia and modern conflict. Conversely, both upper and lower limbs had higher prevalence in the OIF sample rather than the Bosnia sample, potentially reflecting the nature of explosives used in Iraq which have commonly been of the IED type, similar to landmines, which have a high prevalence of lower limb injury (Nelson 2008; Ramasamy 2008; Kang et al. 2011; Navarro Suay et al. 2012; Wallace 2012).

In Afghanistan, foot and femoral trauma was found to be significantly different. Linked to the high use of anti-personnel and anti-vehicle IED's in Afghanistan, the prevalence of trauma to the feet was 17 times higher in this conflict than in Bosnia. This shows a different objective of the intended trauma which in Afghanistan is intended to disable and has produced a pattern with resemblance to that found in land mine injury (Jacobs et al.; Wallace 2012). Femoral trauma in the Bosnia sample was nearly four times higher, marking an interesting distinction that can be explained by the nature of the blast trauma related to RPGs in the Kravica Warehouse case. These explosives were shot into the building through the broken down door. Evidence of this was found against the wall, at waist height, and would consequently be expected to cause a high number of trauma to the femoral or pelvic areas (Headley 2001).

7.3.2. Terrorist incidents

Examining enclosed context terrorist incidents is important in the comparison of the Bosnia results to assess the similarities or differences in the patterns observed. The cases which are used in the Bosnia sample are from a partially enclosed context, which is likely to have affected the blast ballistics and would have had influence on the pattern of injury.

In this context, having examined the data from three studies (Waterworth and Carr 1975; Mallonee et al. 1996; Lambert et al. 2003), significant differences were found in the upper limbs, torso and lower limbs. In all cases, trauma to these body regions was found to be higher in the Bosnia sample. A likely explanation for this would be the number of explosions occurring. In the studies, these were single blasts whereas in the Bosnia samples, multiple RPG's were used, causing multiple blast foci which would cause a pattern with high prevalence, again particularly in the waist area, targeting the general area of the torso and lower limbs immediately around this.

Three other contexts were examined which dealt with bombings occurring in open places (Hadden et al. 1978; Rignault and Deligny 1989; Weil et al. 2011). In the Israeli context examined by Weil *et al.*(2011), frequently a suicide bombing, the trauma pattern was found to be significantly different across the whole body. Trauma to the extremities and torso were common in the Bosnia sample; however, torso and neck trauma was more prevalent in the Israeli contexts. This is most likely to reflect that nature of a bombing in an open place, with the force of the blast escaping in all directions rather than in the more targeted manner of RPGs in the enclosed Kravica Warehouse. In the Paris bombings, all body regions except for the lower limb were significantly different, with a very high prevalence in the Bosnia sample comparatively. The Paris bombs were small improvised devices with only a small amount of explosive material. Bombs of this type produce a diffuse soft tissue injury pattern rather than a large bomb which has higher potential to cause skeletal injuries (Rignault and Deligny 1989).

7.3.3. **Summary of the clinical literature comparison**

This section demonstrates the similarities and differences between various contexts and the trauma prevalence in the Bosnia sample. When comparing the sample to that which is found in combat contexts, there are clear differences in both historical and modern conflict which indicates that the trauma seen in the Bosnia cases is not combat related.

Additionally, significant differences with various other terrorism contexts have been identified which shows that the cases in Bosnia are particular and do not represent the typical patterns seen in terrorism. Overall, both the combat and terrorism situations are significantly different statistically in many body regions making the Bosnia cases quite unique to study and the pattern seen is atypical and unlikely to be combat related.

7.4. Guidance for the assessment of blast injury

An important aim of the research was to formulate guidance for the assessment of blast injury in anthropological practice, thereby engaging the expansion of trauma analysis in the discipline to a type of injury which has seen its prevalence rise. Due to this, in future investigations such as combat archaeology, human rights work, terrorism and forensic investigations, the anthropologist may be faced with the identification and differentiation of this type of trauma. The following outlines guidance for the identification of blast trauma in various situations in which an anthropologist may called to participate.

7.4.1. Assemblages of suspected blast injury- patterns of injury

Examining an assemblage of suspected blast injury should look at the prevalence of injuries to the body regions in the whole assemblage in the first instance. Based on the data available in the literature, Figure 7-1: Patterns of injury prevalence in terrorist incidents and combat related casualties represents the differences between two types of blast-related incidents which can help to identify blast trauma in an assemblage of skeletonised remains.

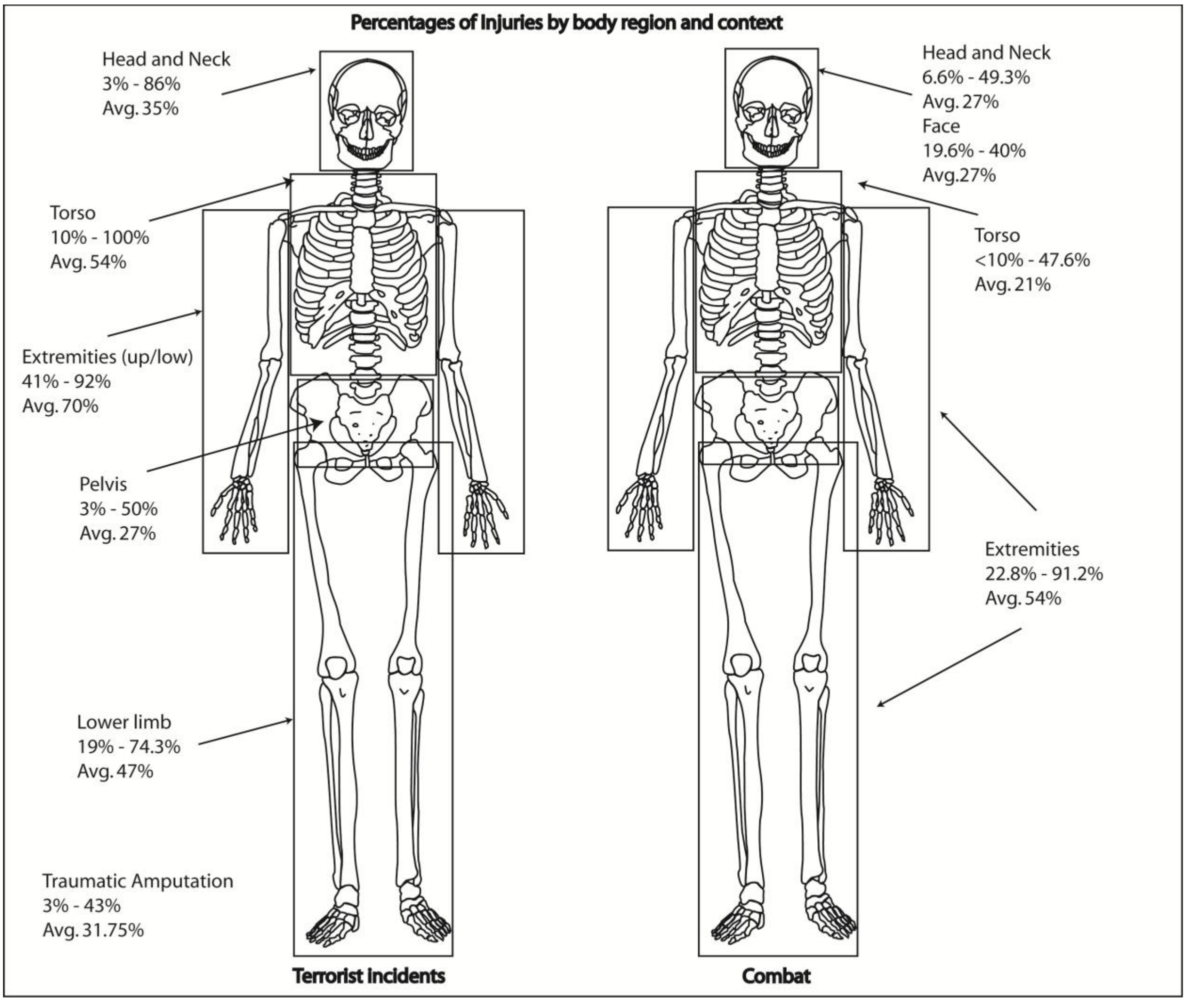

Figure 7-1: Patterns of injury prevalence in terrorist incidents and combat related casualties. Areas of particular interest are the torso and the extremities in the terrorist incidents.

Combining this with the results of this piece of research, a clearer picture guiding the anthropologist in the identification and differentiation of blast injury is seen. In the case of the skeletonised remains from the Kravica warehouse case, both cluster analysis of the variables examined and the multiple correspondence analysis reveals a pattern of injury which shows that the head variables (neurocranium, maxillofacial and mandible) are related, as well those associated with the torso. Whilst this can be related to their close proximity in the body, this pattern is also seen in the case of terrorist incidents which have a high prevalence of blast injury to the torso and head, both areas which are unprotected.

Based on the results of this research and the analysis of the patterns seen in the Bosnia sample, the anthropologist examining assemblages of suspected blast injury can look for a diffuse pattern of injury, with fractures to many areas of the skeleton.

7.4.2. Differentiation of blast injury and gunshot wounds

The results in this research are particularly useful in differentiating between blast injury and gunshot wounds in an assemblage of skeletons. By employing methods which focus on the exploration of patterns within an assemblage of known trauma, differentiation between the two causes of death was established. Particularly, the multiple correspondence analysis helped to identify areas of trauma in the assemblages which demonstrate the differences between the two. These were the head and torso related variables. These were associated with a high number of gunshot wound cases, particularly due to the targeting of these areas as lethal and causing severe trauma to vital organs.

One of the important visual differentiations found between blast injury and gunshot wound in examining the cases from the Kravica warehouse was in the level of comminution in the trauma. In the gunshot wounds, the severity of the comminution was much higher, with smaller and more numerous fragments. This should be considered when the anthropologist is seeking to differentiate the trauma seen in the grave. Additionally, further study should be undertaken and the researcher is exploring the possibilities for the measurement and quantification of the fragments in the Bosnia cases. General guidance for anthropologists, based on the observations made during the research, is that blast produces large fragments in long bones, which number much less than those seen in gunshot wounds.

7.4.3. Differentiation of combat and civilian patterns of injury

A main aim of this research was the differentiation of civilian and combat blast injury, particularly for court purposes. By examining multiple contexts of combat-related blast trauma, guidance has been established for the identification of combat-related blast injury and its differentiation. A summary of the conclusions from clinical literature is presented below in Table 7-1.

Table 7-1: Summary of injuries in combat-related contexts.

Study	Context	Blast injuries	Additional Conclusions
Lin *et al.* (2004)	Afghanistan	65% fragmentation injuries	
Navarro Suay *et al.* (2012)	Afghanistan	Trauma to all regions except head, limbs most affected	
Gofrit *et al.* (1996)	Lebanon	64% front/middle of torso. Front of head 70%	
Ramasamy *et al*. (2011)	Enclosed combat (ie. Tank, armoured vehicle)	Predominantly lower limb.	Tibia, fibula, foot affected. High # of tertiary trauma
Owens *et al.* (2008)	Iraq and Afghanistan	High predominance of head/neck injury in explosives casualties. High # of extremity injuries.	Thorax injuries most common in gunshot
Gondusky and Reiter (2005)	Mechanised battalion, Iraq	Head and upper extremity injury	Vehicle provides protection to rest of body
Jacobs (1991)	Dismounted combat troops	Traumatic amputations (predominantly proximal lower leg/distal thigh)	Pelvic ring fractures noted in bilateral traumatic amputations
Lambert *et al.* (2003)	Confined space (USS Cole)	61% lower limb injury, 40% survivors with orthopaedic injuries	Open fractures predominant in lower limb

Combat-related blast trauma is particularly reflected in the head and extremities. This is a reflection of the various methods of protection offered by modern body armour. This may not be relevant in the anthropological examination of historical combat, such as that seen in WWI. By employing this sample, comparison is made with a sample that did not have the luxury of extensive body armour and replicates some of the conditions of the Bosnia casualties better. The examination of these two samples yields areas of the body to examine when attempting to identify blast injury in unprotected civilians. Again, looking for trauma in the torso region, particularly the vertebrae and pelvis is important.

Extremities also figured as an area of significant difference, with trauma to these being very prevalent in the Bosnia sample.

When differentiating combat-related blast injury versus civilian injury the most important consideration would be context of the assemblage. The variety of patterns in different types of combat means identification of blast injury is contingent on characteristics of this. The use of body armour is very influential in the pattern of trauma, protecting to the torso area. Whereas modern combat had a high number of upper extremity trauma, the Bosnia sample had a lower prevalence. Foot trauma is also frequent in combat-related casualties and would be a good indicator of combat-related blast, particularly due to the use of improvised explosive mines, for the anthropologist to make note of in an assemblage.

Of particular note is the high prevalence of femoral trauma in the Bosnia sample, linked to the use of the rocket-propelled grenade weapon. The knowledge that a weapon of this type was used was confirmed by the pattern of high trauma to this area. Trauma to this area combined with potential use of this type of weapon should be looked for by the anthropologist working on an assemblage of this nature.

7.4.4. Direction for the reporting of injuries in clinical settings

Despite the challenges associated with the reporting of blast injuries in the clinical context, such as the scale of the number or casualties and the time for reporting during a case, certain aspects of the description of injuries could be beneficial to future anthropological research.

Particularly relevant would be the description of the fractures themselves, adding a new dimension to the analysis of the patterns which goes beyond the identification of body regions injured. Observations regarding differences from gunshot wounds found in blast-related cases leads the researcher to examine the possibility of quantifying the fragmentation of blast injuries. As such, describing the dimensions of the fracture, type of fracture, and directionality would be beneficial. Direction of impact, be it from the blast wave or shrapnel fragments, contributes a wealth of knowledge which would aid in contextualising the events greatly.

By expanding the recorded data in clinical cases and studies with the above, a clearer picture of the patterns could be constructed, particularly looking at differentiating the types of fractures induced by blast waves and how these may differ from gunshot wounds.

7.5. Evaluation of the results

Critical examination of the research was undertaken to assess different aspects of the results such as their significance, strengths and weakness, and overall relation to previous conclusions from the literature.

The significance of this work is important to note, particularly in light of the increasing use of explosive materials and munitions in numerous contexts. Combat and terrorism figures predominantly around the world and we have become increasingly familiar with the use of explosive munitions. Due to this, knowledge about the trauma inflicted by these is required in a variety of fields and will become necessary in anthropology as well. Currently, in anthropology, very little has been published with the exception of a few peer-reviewed articles and book chapters (Kimmerle and Baraybar 2008; Christensen and Smith 2012; Christensen et al. 2012). Blast trauma analysis will become an increasingly important aspect of anthropology with applications in human rights work, combat archaeology, terrorism investigation and mass disaster work. With this research, an important gap is addressed by beginning the definition of blast injury in anthropological contexts and exploring the patterns which contribute to the identification of this unique trauma. This is accomplished by examining a statistical methodology which has been used in other disciplines, or subsets of anthropology and archaeology, to identify and differentiate between blast injury and gunshot wounds and to classify patterns in a blast trauma assemblage.

The findings in this research concur with the main source of information regarding blast injury, clinical studies. As is seen in the literature, a diffuse pattern of injury is most likely to be seen in blast injury assemblages. In the Bosnia sample, it is also the body regions which are less vital which has blast trauma, particularly compared to the high prevalence of trauma to the head and torso area in the gunshot cases. Conversely, when examining combat trauma samples in the literature, the overall pattern of trauma is statistically different in all contexts examined to the injuries in the Bosnia sample. This serves to answer the question regarding the nature of the trauma in court cases where the stipulation was made that the casualties were combat related. Additionally, the results can be generalised to give guidance on the differentiation and identification of blast injury by contributing data on yet another complex series of events.

By employing statistical methods, the research produces results which could potentially be replicated and cross-validated, even if this cannot be done at the moment due to a lack of samples. Employing statistical methods also permits the presentation of the results in court, satisfying evidentiary rules. Using multivariate statistics has also minimised error which can be introduced in the traditional χ^2 comparisons.

7.6. Issues/limitations

As with research, issues and limitations require addressing. This piece of work is not without limitations and the author recognises these. The majority of these limitations are due to the nature of the sample the research is based on. The Bosnia sample has its limitations, however these can be addressed.

Issues relating to the validity and reliability of data sources have been examined. In the use of statistical scientific methods, the replication of analyses or experimental work is of great importance. In this research, reliability of the data was focused on, particularly in the data from the Bosnia sample where each case was examined with multiple sources, such as the pathology reports and the associated photography to ensure the conclusions in the report were valid. The size of the sample was adequate and represents a large sample, particularly taking into account the novel nature of the examination and the exploratory methods employed to being the examination of blast injury in the context of anthropology. The sample also takes into generalisability of the results in this study. It is believed that as an exploratory phase of research and a first step in describing and guiding the assessment of blast injury

The medical management focus of the clinical sources poses problems in the recording and reporting of the data associated with blast injury. Frequently, studies present data on either fatalities or survivors, focusing on specific groups while ignoring the other from particular incidents. This could potentially lead to a bias, particularly in deceased samples, which may have more severe injuries and may skew the results to having a differing pattern, possibly one which represents a greater number of injuries causing death. Reporting the clinical data from survivors may skew the information conversely. Due to this, the data taken from clinical sources was taken from both types of studies to minimise the chances of bias towards either possibility.

The medical management focus of clinical studies can also impact the type of data available in the literature. Data collected is likely to centre around the soft tissues, as show by the high number of studies which deal with the consequences of primary blast injury to the vital organs. Orthopaedic information revolves around the treatment of skeletal injuries rather than the systematic description of the injuries revealing the importance of post-incident intervention in medical teams. Additionally, the nature of these incidents being very complex and requiring a large number of hospital resources is likely to impact the type of data and recording being done during these cases. This may affect the reliability and completeness of the information being catalogued in medical files, impacting the availability of data for clinical studies. If it has not been recorded during the medical management, it cannot be utilised in studies subsequently, at least not reliably.

One of the important issues in using a sample that is related to human rights cases or even mass disaster is the limitations of data recording (Arnold et al. 2004). Whether affected by time limitations or sheer number of cases, this can affect the accuracy or preciseness of what is recorded. Whilst the highest level of information was sought by the researcher, relying on data from secondary sources, as in the autopsy reports, this can pose issues. To overcome this limitation, multiple sources for each case were consulted. Pathology reports were combined with autopsy photographs to improve the accuracy of the data derived. All cases have autopsy reports but not all of these have associated photographs. This poses a problem as all trauma in the reports is re-assessed, by the author, through examination of the autopsy photographs to confirm the anthropological assessment of trauma. By not using photographs, the introduced bias can increase greatly by relying on information which is based on an assessment made by a pathologist who may not be as experience in skeletal trauma and the differentiation between perimortem and postmortem changes.

Complicating matters however is that rejecting the cases that cannot be confirmed through photographs reduces the sample size considerably. This did not pose a problem as the level of access to information permitted thorough reconciliation of the data from multiple sources.

This highlights the same potential problems in further investigation, whether using a military, clinical or anthropological source. The analysis will only be as good as the available data and can suffer when key information is missing. However, as even acquiring the current data is an important positive step, it is the beginning of structured consideration of an important aspect of anthropology previously ignored and serves as the basis for the evaluation of potential analytical methods which can be built upon subsequently.
The issue of using pathological data highlights problems in the identification of ante-mortem, peri-mortem and post-mortem trauma. The assessment of the timing of trauma ultimately belonged to the pathologist (who worked in conjunction with anthropologists) in the Bosnia cases. The anthropologists contributed by providing a biological profile, leaving the majority of trauma identification to the pathologists. In skeletonised remains, it would be possible that the pathologists would overlook indicators that differentiate between the ante and post-mortem injuries due to lack of experience with this assessment. Ultimately, this was unlikely to affect the final diagnosis of cause of death, which was determined by the pathologist. For this piece of research, re-examination of the specific injuries attributed to the various mechanisms was necessary to ensure that findings to be included in the data were peri-mortem in nature. This was achieved by examination of the large number of autopsy photos available in conjunction with the autopsy reports (including anthropological information). It is however entirely plausible that some assessment may have been inaccurate. If there is a distinct discrepancy between the pathology report and autopsy photographs identifying peri-mortem skeletal trauma, the determination rested with the author, so long as the evidence can be supported. If a positive determination of the trauma cannot be made certainly, this particular injury and case was omitted from the data. This can pose problems which introduce observer bias into the data and make the sample smaller. However, it was important to achieve the best accuracy possible in the identification of blast trauma and as such cases with any doubt as to the nature of the trauma were omitted.

Sample size always remains an issue in anthropological research. This is relevant here with the relatively small sample size of the cases with blast injury. The total sample size of 48 can be viewed as being small for certain disciplines but in anthropology it is not unheard of to have much smaller sample sizes (Schweizer and Lang 1989) or individual case studies. Despite this, the size of the sample in this research is very good. Materials with blast injury are extremely scarce, particularly those which are of an anthropological nature. No other materials of this nature have been examined in such a quantity by an anthropologist.

The scarcity of known examples blast injury also poses the problem of testing any statistical models built through the research presented in this thesis. Scientific theory stipulates that testing of these models should be undertaken, however due to the difficulty in having access to even the data which forms the basis of this research, this would be impossible at the current time. As such, the models and conclusions proposed need to be further investigated at a later time, including the cross-validation of the predictive binary logistic regression model. Publication of the research presented is being undertaken in the hopes of expanding its reach and testing the conclusions achieved here. An article has been accepted by the Journal of Forensic Sciences and is in press (Dussault et al. In Press).

Specific issues regarding individual skeletonised remains are also a concern. Many of the cases in the Bosnia were incomplete skeletons. This can cause a certain amount of bias as these cases may not represent all body regions which have actually been injured due to the lack of preservation and recovery of the remains. This can also be caused by the movement of remains from primary to secondary graves. As such, cases which represent body parts rather than complete skeletons will cause a bias towards the absence of evidence of blast injury due to an absence of body regions being noted as an absent body region/absent of blast injury where it cannot be assessed. This can cause problems in the representation of the patterns but still remains that due to the lack of current data regarding blast injury in anthropology, it is still important to attempt to use the information to contribute in the start of establishing methodology to be used in the assessment of trauma in assemblages. In the end, only one case was included, GL01/502BP. Concerns regarding commingled remains were also addressed. Cases which represent more than one individual included in the autopsy forms were not used as these represent more than one person and these cannot be separated into individual cases. Each case in the database represents one person only.

Statistical limitations were also acknowledged. In particular, the use of the Holm-Bonferroni correction reduced the power of finding any significant differences between the groups because the α value has become very small with such a large number of variables compared. A solution to this would be to use a multivariate technique to reduce the number of pairwise comparisons. Using multiple correspondence analysis has addressed this and has shown that this method can identify associations that were not revealed using multiple pairwise Pearson's χ^2.

Cluster analysis also posed issues. Employing the mathematical criteria as laid out in the methodology chapter, the solutions indicate a certain number of solutions; however, examining the dendrogram visually additional patterns appear within the data. In the case of clustering the blast injury cases solely, an alternate solution appears with four or five possible clusters with may indicate useful sub groupings. Particularly, the larger the sample became, as was the case with the gunshot, the more difficult it was to interpret.

Context of the cases and unknown variables were likely to have played a part in the analysis of the Bosnia cases. Particularly, additional information regarding the patterns of injury could have been gained from having location information for each of the cases in the Bosnia sample, such as where the men were standing at the time of death. However, this was impossible given the nature of the sample. Linked to the nature of the sample are post depositional issues. Taphonomic changes could have certainly affected the skeletonised remains, particularly those involved in the movement of the remains from the primary grave to the secondary grave. Particular care was taken in the identification of peri-mortem trauma in the pathology reports, autopsy photos and combined with the archaeological data available in the site reports. The likelihood that these issues can have affected the sample is important, but efforts to negate this were put in place. By the very nature and rarity of this sample, ignoring the potential for research because of these issues would have prevented an important first step in the development of knowledge for the discipline.

It is also worth noting the complexity of blasts and explosions. Many variables are at play which contributes to the patterns of injury. This makes comparison between different blast situations difficult. Too many variables may be at play, interfering with the amount of specificity that one is capable to achieve. The variables attached to these types of incidents range from the type of weapons used, to the specifics of the situations (such as the location) and human factors (ranging from clothing, to body type, size, and height). Further research is needed to expand the data and build these various factors into analysis. Anthropology does not have a body of knowledge on blast injuries currently in the literature and despite not achieving very specific results when it comes to injury identification but rather differentiation of patterns, the research is still valid in that it address the dearth of information regarding this and highlights the need for continuing work on this type of trauma.

8. Conclusion

This study was developed to examine blast injury in the human skeleton and apply robust multivariate statistical methods, alongside morphological methods, to identify blast trauma based on the distribution of injury in the skeleton. Anthropologists are now involved in cases dealing with blast trauma from both civilian and combat contexts, such as terrorism or war zones like Afghanistan. However, anthropological literature has not addressed the recognition and identification of blast trauma, with the exception of limited case studies and one experimental study (Kimmerle and Baraybar 2008; Christensen and Smith 2012). This has left a gap in the current knowledge regarding blast injury. Currently, research on this type of trauma is centred predominantly on clinical literature and medical management of this trauma.

Due to the lack of knowledge regarding blast injury in the skeleton, questions have arisen regarding the nature of this trauma. This is particularly exemplified in the courtroom debate at the International Criminal Tribunal for the Former Yugoslavia which brings into question whether blast injury deaths were human rights violations or combat-related. Knowledge of this type of trauma, the patterns expected in an assemblage of skeletonised remains and indicators of blast injury are of important to both forensic and biological anthropology.

To accomplish the aim of this piece of research, four objectives were identified:

1. An exploration of patterns of injury previously published in clinical literature.
2. The establishment of a statistical methodology to compare observed patterns of injury in assemblages for the purpose of identification and comparison of blast injury in various contexts.
3. Application of the statistical methodology to the discrimination of blast injury from gunshot wound related deaths with the purpose of providing indicators to differentiate the two types of trauma.
4. Application of the statistical methodology to a large scale assemblage to explore the patterns present and compare these to the previously published data in the clinical literature to assess if the patterns in the assemblage are similar or different to those found in blast-related combat trauma.

5. Formulation of guidance for the identification and differentiation of blast injury in skeletonised remains.

The first objective required a thorough examination of the clinical literature for information which was applicable to the identification and differentiation of blast injury in the human skeleton. The history, physics and chemistry of blast were explored to contextualise the development of explosives and the changes over time which produce the injury mechanisms were see in modern explosives. The biomechanics of blast and patterns of injury were explored, detailing the biological response of the human body to explosions along with the patterns of injury seen in contexts of terrorism and combat. This information was collected and compiled to compare prevalence of trauma in these contexts with the examined samples.

Statistical methods were examined and tested to formulate a methodology for the differentiation and identification of blast injury in large scale assemblages. The traditional method used in trauma analysis, Pearson's χ^2 test was used to examine prevalence differences between two samples from mass graves in Bosnia. This compared cases of blast injury and gunshot wound related deaths. Significant differences were found in a small number of body regions. Graphical methods of pattern identification were employed to explore the two samples and identify and differentiation which may be of use to the anthropologist when comparing these two causes of death in large samples. Cluster analysis was employed but failed to yield distinctions directly between the individual cases, potentially due to issues of sample size which rendered interpretation of the analysis difficult. The second approach with cluster analysis was to examine the variables rather than the cases, and this yielded results that pointed to groupings in the variables, such as those of the skull area and the bilateral siding variable.

The third objective sought to use statistical methods to differentiate between the two samples from Bosnia, the blast injury and gunshot wound death cases. Multiple correspondence was employed to identify variables which contributed significantly to variance between the two groups. This analysis yielded a set of variables, larger than those identified in the Pearson's χ^2 and cluster analyses. Multiple variables were found to differentiate between the two causes of death, particularly the limb variables, which echoes the conclusions of the clinical literature. These variables were employed as indicators in a probability model using binary logistic regression to attempt to classify cases as having blast injury or not. Additionally, two methods of binary logistic regression were employed, to test whether or not predetermined indicators or a computer generated model yielded the best results. No significant difference was found between the two methods. It was found that the extremity variables were significant contributors to a predictive model which had a 74.86% classification success.

The fourth objective required comparison to the clinical literature to identify similarities and differences in the Bosnia blast injury cases sample along with a sample of World War One cases. This further enabled the identification of differentiation characteristics in blast injury. Problematically, direct comparison of identified patterns was not possible as the clinical literature did not have the same level of detail as the Bosnia sample compiled by the current researcher. Prevalence comparison of simpler variables was undertaken and employed Pearson's χ^2 analysis. It was found that there were significant differences in the prevalence of the distribution of trauma between the Bosnia sample, the World War One sample and the clinical literature. This demonstrated that the Bosnia case was particularly unique and this was likely due to the context, which involved the use of rocket-propelled grenades and a partially enclosed building. Both these factors contributed to a distribution of injuries were not like those in terrorism. This examination also served to answer the important question of whether or not the deaths were combat related, an argument which has been raised numerous times in the ICTY court proceedings. It was found that statistically there were significant differences between the Bosnia sample and a variety of combat contexts.

The fifth objective is met by presenting the results and guidance regarding the identification of blast injury and its differentiation from gunshot wounds. The guidance also includes direction on the differences between combat and civilian related blast injury to aid in the assessment of the patterns of injury in assemblages, particularly in the case of human rights abuses.

The conclusions drawn in this thesis contribute to the knowledge of blast injury in the forensic and biological anthropology contexts. Through the use of known cause of death samples, it was demonstrated that the patterns of injury can be analysed using graphical patterns detection methods such as multiple correspondence analysis to identify body regions which can predict the presence of blast injury in an assemblage. Particularly, trauma to the extremities significantly indicates the presence of blast injury and trauma to the maxillofacial, mandibular and vertebral body regions indicated the presence of gunshot trauma. This contributes by identifying regions of trauma to look for when examining a large scale assemblage with suspected blast injury.

Additionally, the use of multivariate methods of analysis has shown that significant differences in a trauma assemblage can be missed when using pairwise Pearson's χ^2. This is due to the need of a statistical correction to counter the issue of inflated Type I error which occurs when undertaking multiple consecutive pairwise comparisons. These methods also permit the examination of interactions between variables which can be at play in large assemblages. As such, it was deemed that these methods of statistical analysis can be useful in trauma analysis and could be used on a variety of samples, from multiple time periods and provenances, which could highlight interesting patterns of injury which may not have been explored previously. These methods can also be expanded to incorporate other anthropological relevant variables, such as demographics, to provide larger picture analyses rather than individual examinations which form part of the basis of trauma analysis in forensic and biological anthropology.

The implications of these conclusions are multiple for anthropology. The results attained can contribute to investigations of terrorism in which anthropologists are increasingly requested to contribute. Strategies for recovery may also be impacted, indicating which areas of the body may be fragmented and guiding the need for thorough searches focused on these. Experimental work can be directed to look at the impact of explosions on the body regions which are most likely to be injured and specific examinations of the fracture patterns and fragmentation can be approached.
As was raised in the limitations section, future research lies in the possibility of access to samples with blast injury. This is a very difficult point; however certain future research directions have been identified. More comparisons of the patterns of injury in blast trauma need to be undertaken. This may mean collaboration with clinicians to gather information and exploring the experimental route, which has begun with a previously published paper using pigs as proxies (Christensen and Smith 2012). Addressing the specificity of the trauma to the skeleton is an area where the author would like to undertake work. Particularly, comparison of the size of fragments in blast injury and gunshot wound cases is being developed with the data used in this thesis.

The methodologies approached in this thesis can serve as valuable tools when exploring assemblages. This can serve to analyse other types of trauma and explore relationships beyond the physical characteristics of the trauma. These methods permit a variety of variables to be analysed to form conclusions about assemblages, whether these are burial characteristics, biological profile, and disease prevalence along with the analysis of trauma. The application of multivariate statistical analysis of assemblages for the examination of patterns of injury is being explored as a further area of research expanding on the work undertaken here. Examination of the patterns of injury in assemblages across time as well as regions will be undertaken, comparing the prevalence of trauma between groups and within groups, as well as the nature of the trauma to note any temporal or geographical similarities or differences between groups.

This thesis has shown that the application of robust statistical methodology can be employed to identify blast injury in a large skeletal assemblage. This identified areas of the body which have different patterns of injury which can serve to differentiate blast injury from gunshot injury in skeletonised remains, an aspect of anthropologic which has not been explored previously. Additionally, this work has also answered specific questions, comparing and contrasting the clinical literature and quantifying significant differences in prevalence of trauma between a known sample and those found in various contexts such as terrorism and combat. This has served to answer the question of the nature of the trauma in the sample, identifying that the Bosnia sample was significantly different from combat blast injury context. This thesis has contributed to forensic and biological anthropology by reaching objectives which have contributed to specific knowledge of blast injury and its patterns, methodology for the examination of blast injury and large scale assemblages, and answered questions relevant to anthropologists' work in human rights investigation.

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Appendices

The appendices can be located on the attached CD-ROM and include:

Appendix A: Bosnia Data

Appendix B: World War One Data

Appendix C: Bosnia Data- recoded

Abbreviations

MPa - MilliPascal (unit of tensile strength)

Ms - Millisecond

MHN - Mannitol Hexanitrate

PETN - Pentaerythritol tetranitrate

TNT - Trinitrotoluene

RDX - Cyclomethylenetrinitramine (also known as Cyclonite)

C-4 - Composition C4

ANFO - ammonium nitrate fuel oil

PIAT weapon - projector infantry anti-tank

ICMP - International Commission on Missing Persons

ICTY - International Criminal Tribunal for the Former Yugoslavia